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FINAL REPORT

ASSESSMENT OF THE APPLICATION OF ADVANCED TECHNOLOGIES TO SUBSONIC CTOL TRANSPORT AIRCRAFT

prepared by

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16. Abstract

Prior to this contract, three airplane manufacturers had accomplished design studies of the application of advanced technologies to future transport aircraft. These studies were reviewed from the perspective of an air carrier. A fundamental study of the elements of airplane operating cost was performed, and the advanced technologies were ranked in order of potential profit impact. Recommendations for future study areas are given.

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TABLE OF CONTENTS

SUMMARY

A thorough review has been made of the Advanced Transport Technologies (ATT) studies performed by three airframe manufacturers. Because of the nature of the material presented and the need for a common denominator, economics plays a major role. Although economics was not the only factor examined, it was the main factor used here to summarize the potential benefits of applying advanced technologies because of its importance in commercial air transportation.

There was found to be a potential benefit accruing to the primary technology areas investigated. In defining this potential, American Airlines used only economic and design data emanating from the General Dynamics studies, at the instruction of NASA-Langley. However, the economics and designs of the other two contractors, the Boeing Company and Lockheed-Georgia were also evaluated.

The profit potential was obtained by isolating the appropriate technology area and measuring the margin over conventional technology generated by inclusion of that element. A relative ranking could be obtained by applying this measure against a present technology aircraft having a 195 seat configuration. It is stressed, however, that this study is based upon certain assumptions (see Figure 7A & 7B) which would have to be adhered to for such a comparison. The profit margin impact places the following values on the technology areas reviewed.

PROFIT MARGIN IMPACT
(Passenger Load Factor - 50%)

1972 $

Primary Technology Areas	Profit Margin Impact Δ ¢/RPM
o AIRFRAME	
Composite Structure (1972 Engine)	0.4092
Composite Structure (1978 Engine)	0.4304
Composite Structure (1982 Engine)	0.4188
Supercritical Airfoil (Alum AF)	0.3820
Active Control System (Alum AF)	0.0740
Active Control System (G/E AF)	0.0560
o ENGINE	
Present Technology Airframe Materials	
Advanced Engine 1978	(0.0368)*
Advanced Engine 1982	0.2632
Advanced Technology Airframe Materials	
Advanced Engine 1978	(0.0348)
Advanced Engine 1982	0.2536

(*) Denotes Decrease.

An engine technology impact was also reviewed to complete the study even though this was not part of American Airlines' task. It was felt that this element was essential to make a meaningful assessment of the effect of other advanced technologies.

One of the major impacts to the airline could be the effect of increased speed. This was considered in great detail because, the implication of a reduced number of aircraft with higher utilization posed

a potential benefit. Several steps were taken from the general effect of increased speed, to the integration of a 0.98 Mach aircraft into American Airlines' route network. It was found that the potential benefits were only small improvements in scheduling flexibility, with no elimination of aircraft from the fleet or added scheduled trips (increased utilization).

An operational cost study was performed using American Airlines data to determine where future advanced technology research should be focused. The basic elements of cost were examined to focus on the origin and magnitude of airframe related expenses. This was accomplished to establish a priority of future study areas. The high operating cost areas were found to be Systems, Secondary Power and Landing Gear. The latter points out a fundamental part of the airframe that has been overlooked from a cost point of view, as designs have progressed.

Finally, the manufacturers' underlying postulate as to the economic value of any particular technology, and the change in value attributed to substitution, is a costing methodology predicated primarily on acquisition price and weight. This costing approach has not been found to be representative. The theory that small cost changes (derived by formula) were reflective of the technology introduced, however, was accepted and formed the foundation upon which American Airlines assessed the profit impact. It was concluded that future economic evaluations will require better methods to assess operational costs.

INTRODUCTION

Almost without exception, agreement can be found about the role Technology has played in the commercial aircraft sector of the United States economy. Also, there would be agreement that investment in any technology for future use is warranted. The spending of funds in the area of technology for future period utilization is in a way the investment in an asset. As in any exploration into "asset worth" past and present, measurable quantities are used in an attempt to, as precisely as possible, determine future utility. In the case of commercial aircraft, the air carriers study the past performance of their fleets and the benefits that may have accrued from designs peculiar to a specific vehicle model.

Accordingly, American Airlines has used past and near term hisotry of its inventory of aircraft to consider the factors upon which three contractors (The Boeing Company, General Dynamics and Lockheed) have projected benefits resulting from certain technologies.

American Airlines has evaluated the conceptual differences in design and economics in light of their past experience. We have recognized the objective to assess the benefit that may result from expenditures for research and development in the various technology areas presented and maintained an objective stance. Internal records were used to substantiate positions taken. It was not our objective to prove or disprove any of the contractor's work but to provide NASA a perspective from a potential owner of the next generation aircraft. In this regard, American Airlines presents this report as a continuing stimulus for careful detail study of technology advancement that can be banked for future utility.

SYMBOL LIST

MZFGW	- MAXIMUM ZERO FUEL GROSS WEIGHT
EOW	- EMPTY OPERATING WEIGHT
STR LIM	- STRUCTURAL LIMIT PAYLOAD
SP LIM	- SPACE LIMIT PAYLOAD
MLN WT	- MAXIMUM LANDING WEIGHT
PL	- PAYLOAD
PSGR	- PASSENGERS
M_D	- DIVE MACH NUMBER
NM	- NAUTICAL MILES
KM	- KILOMETER
SMI	- STATUTE MILE
ASM	- AVAILABLE SEAT MILE
ASK	- AVAILABLE SEAT KILOMETER
RSM	- REVENUE SEAT MILE
RSK	- REVENUE SEAT KILOMETER
LB	- POUND
LF	- LOAD FACTOR
ATA	- AIR TRANSPORT ASSOCIATION
DOC	- DIRECT OPERATING COST
IOC	- INDIRECT OPERATING COST
TOC	- TOTAL OPERATING COST
BAG	- BAGGAGE
ALIM	- ALUMINUM
S/C	- SUPERCRITICAL AIRFOIL
G/E	- GRAPHITE EPOXY
ACS	- ACTIVE CONTROL SYSTEM
RH	- RAMP HOUR

SYMBOL LIST (Cont'd)

M_{MO}	- MAXIMUM OPERATING MACH NUMBER
RPM	- REVENUE PASSENGER MILE
TBC	- THE BOEING COMPANY
GDFW	- GENERAL DYNAMICS, FORT WORTH
FAA	- FEDERAL AVIATION ADMINISTRATION
EPA	- ENVIRONMENTAL PROTECTION AGENCY
FAR	- FEDERAL AVIATION REGULATIONS
SST	- SUPERSONIC TRANSPORT
VTOL	- VERTICAL TAKE-OFF AND LANDING
APU	- AUXILIARY POWER UNIT
IEG	- INTERNAL ENGINE GENERATOR
GLAC	- LOCKHEED-GEORGIA CO.
C_L	- LIFT COEFFICIENT
C_D	- DRAG COEFFICIENT
ATT	- ADVANCED TRANSPORT TECHNOLOGIES
ATC	- AIR TRAFFIC CONTROL
EPNdB	- EQUIVALENT PERCEIVED NOISE LEVEL (DECIBELS)
SFC	- SPECIFIC FUEL CONSUMPTION
GMT	- GREENWICH MEAN TIME
ATM	- AVAILABLE TON MILE

AIRPORT CODES

ACA - Acapulco, Mexico
MEX - Mexico City
BOS - Boston, Mass
ORD - Chicago (O'Hare)
DAL - Dallas
DTW - Detroit
LAX - Los Angeles

JFK - New York (Int')
EWR - Newark
PHX - Phoenix
SFO - San Francisco
STL - Saint Louis
TUL - Tulsa
IAD - Washington (Dulles)

HNL - Honolulu
PPG - Pago Pago
NAN - Nandi (Fiji)
AKL - Auckland, N.Z.
SYD - Sydney (Australia)
SJU - San Juan
CUR - Curacao
AUA - Aruba

ASSESSMENT

o ATT CANDIDATES

Basically, the job of reviewing the ATT designs is one of (a) determining the characteristics and then (b) determining their worth to the ultimate buyers. Before these two determinations could be made, much information had to be accumulated, organized, analyzed, and interpreted. A logical starting point was to examine the objectives and then to compare the results. Each of the Phase II designs had a set of conditions within which the manufacturers worked. The comments by American Airlines are made cognizant of these limitations.

Each of the contractors (TBC, GDFW and GLAC) produced designs that appeared to meet all NASA outlined design objectives. Each contractor arrived at their resultant positions by narrowing the elements of design through the use of economic considerations. The airframe considerations embraced essentially four different categories of "technologies" — supercritical aerodynamics, composite materials, active control systems, and to a lesser degree, the effect of propulsion technology. The categories were studied to assess their economic value, using an approach that combined physical characteristics (i.e., weight, size, C_L, C_D, thrust, etc.) with an approximation of operational expenses, and return on investment. The economic considerations were predicated primarily upon weight and price. It shall be the approach within this report, to first summarize the physical and then the economic interpretations.

o OPERATIONAL ENVELOPE

Each of the Phase II candidates have the general design features contained in Table 1. The space limit payload values shown, were determined using standard American Airlines unit weight and density relationships. A comparison was made of these with conventional

fleets. To be commercially saleable to a U.S. or foreign air carrier, it is believed that an ATT aircraft will have, at least, to meet present standards.

The ATT aircraft all fall within the payload range envelopes of "conventional technology" aircraft. To go beyond present aircraft in payload or range was not the purpose of the ATT work. It is mentioned because future aircraft will be required to show better efficiency, by some measure, to make them a viable product when compared to present equipment. In this regard, there are certain design features that should be mentioned.

o PAYLOAD

All designs were found to be structurally limited. If the volume available were filled with a nominal density of 160 Kg/M^3 (10 lb./ft.^{3}), the weight of the aircraft would go beyond the design structural capability. A commercial vehicle would not be acceptable to an air carrier under these constraints. Even if the margin between the volume and structural limit were zero or small, it is doubtful if the aircraft would be considered acceptable. There are two reasons for the unacceptability of zero or negative payload margins. The first and most obvious is the limitation of payload. If the aircraft were limited to something below its volume (space) limit, an air carrier would be initially "handicapped." When in service, the operator would have to make a trade between carrying cargo, passengers, or some limited combination of both. This relationship is best illustrated in Figure 3. It can be argued that 160 Kg/M^3 (10 lb./ft.^{3}) is not a norm. If the cargo density were allowed to "float" a comparison can be made of the resultant limiting value. At a 100% passenger load, the density available

for cargo and baggage is shown in Table 2. As illustrated, the ATT aircraft do not meet what is considered a minimum standard for belly cargo.

The second reason for establishing a margin is for "operational growth" which occurs in all aircraft. Although commercial carriers do not normally operate at the space or structural limit, a margin is required to allow for the erosion of payload capability. An aircraft's empty operating weight (EOW) increases with time, usually the result of in-service modifications. As the EOW increases, the structural payload limit (MZFGW - EOW) decreases. If there is no margin, the carrier is faced with an inefficient aircraft from the standpoint of excess volume that cannot be filled. Table 3 illustrates the growth that AA has experienced in its' fleets. The ATT study aircraft have an initial limitation.

o MATERIALS

Since all ATT designs used varying degrees of composite materials, an overall indicator or measure of efficiency was constructed using the structural payload limit. A yardstick by which to measure and compare the ATT composite structures to conventional construction, is the ratio of the maximum structural limited payload to the empty operating weight (STRLIM P.L./EOW). This ratio is shown for both the ATT candidates and conventional aircraft in Figure 4. The ratios for the ATT vehicles were expected to exceed present technology aircraft. This did not occur. A target of increased speed and lower noise may be the underlying cause for being essentially equivalent to conventional aircraft by this measure. It was noted that as the design cruise speed increased, the PL/EOW decreases (see Figure 4). From the strength to weight ratios of composites, it would logically follow that greater payloads should be available at equivalent empty weights. One conclusion is that there has been no deterioration in the payload available due to

noise penalties as a direct result or effect of advanced technologies, since noise reduction is apparently a major contributor to increased weight.

Throughout the tables and figures mentioned, there has been an exception noted. In the GDFW values, a 1.5 multiplier (1.5 Psgr. P.L. = STR. PL) was reportedly used to establish the structural design limits. This appeared to be an arbitrary definition of structural payload which differs from a conventional weight build-up number. It was not clear, from all the material presented, how the payload limit (STRLIM. P.L.) was actually derived. So as not to dwell an unproportionate length of time on this subject, both values are shown for the reader's review.

o AERODYNAMICS

Supercritical aerodynamics offer improvements in weight, through thicker, lighter wings and/or higher cruise speeds with potential increases in range. The design objective would dictate the trade-offs to be made. The only problem area (and this is not exclusively aerodynamic) may be the cruise speed itself. If a supercritical wing is chosen for the Mach range of 0.95 and above, the required dive speed, for present FAR required safety margins, would be supersonic. This could require additional systems (stability augmentations, Mach trim devices, airspeed system etc.) and higher than conventional economic burden. The dive Mach numbers (M_D) of the ATT aircraft are compared to present in-service aircraft in Table 4.

o AREA-RULING

Fuselage area-ruling is required for the higher cruise Mach speed of 0.95 and above. The potential problem with a marketable commercial aircraft is its flexibility to fill the needs of a variety of air carriers. In this regard, the concept of a family of aircraft,

such as for each of the 707, DC-8, DC-9, and 727 types, when applied to area-ruled airplanes, may require a resizing of the vehicle. Simply adding a fuselage section for dimensional growth may not be feasible if the aircraft has to be re-optimized. Area ruling also produces a much less flexible cabin and belly cargo design.

o TIME SAVINGS

The higher speeds brought about by supercritical wing, area-ruling, and composites, offer potential time savings. A theoretical time savings, when compared to a 0.84 Mach cruise aircraft, is about 14 and 39 minutes for 0.90 and 0.98 Mach cruise aircraft, respectively, over a transcontinental range (JFK-LAX). Over a longer range, such as JFK-HNL, the time differentials are 39 and 99 minutes for the two aforementioned cruise speeds. This potential is reduced considerably over a segmented route network by two factors: (a) en route delays and (b) average trip lengths. The ramp-to-ramp times are increased for delays associated with ground taxi, winds, en route flight plan changes, time-of-day of departure or arrival, ground tracks and season of the year. Two aircraft with the same cruise speed can have different schedules times. Conversely, aircraft with different cruise speeds may have identical schedule times, depending on the effect of these items. The other factor is the nominal trip length. Design ranges for the ATT aircraft are about 5500 KM (3000 N.M.) and 9300 KM (5000 N.M.). If these represented averages over some hypothetical network, there would be a potential time savings. In practice, however, average trip lengths are far below design ranges. An example of this is the average stage length for the 747 and DC-10, which was 2846 KM (1537 N.M.) and 1421 KM (767 N.M.) - July 1973 for American Airlines' fleet, respectively. These values represent distances less than half of their design range.

It can, therefore, be seen that unless the average trip distance is what can be considered long-range (5556 KM Plus) the potential time savings deteriorates.

Since the speed advantage appeared to have the maximum advantage at 0.98 Mach cruise, that speed was first selected for scheduling over selected routes. The scheduling analysis had three phases: (a) theoretical fastest times, (b) 0.98 Mach cruise actual times, and (c) a total scheduling exercise.

o FASTEST TIME

Several selected routes were used to compare a 0.82 Mach cruise aircraft to a 0.98 Mach ATT aircraft. No restriction was made for range limitations of the aircraft, for previously mentioned delays, or for preferential departure times. It was an attempt to determine the maximum potential on an actual route flown by a 707-300 aircraft. For a two day cycle, the time differential was 1:22 Hr:Min for a domestic schedule. An international route system, with longer stage distances, resulted in several time savings values depending upon the ground rules imposed. If departure times were allowed to "float", with a restriction of leaving Sydney (see Figure 5) in the morning after the locally imposed curfew, there is a potential of 5:03 (Hr:Min) savings. By turning the aircraft in 2 hours at Sydney, there is a potential time savings of 16:05 (Hr:Min) within the approximate three day cycle. Eight hours of this time savings results from the elimination of the curfew at Sydney. In theory, the 16 hour time differential could allow for an additional trip somewhere else. It should be recognized that these schedules do not allow for special maintenance or servicing problems that may exist, nor was there any attempt to adhere to a prime departure time. Some departures could occur at an undesirable time of day (e.g. 3 o'clock in the morning).

o ACTUAL SCHEDULED TIME

For similar routes, a scheduling model was used with adjusted ramp-to-ramp times. All normal ATC, ground delays, winds, servicing etc., were built into the 0.98 Mach cruise speed. An example of the schedule computer output is displayed in Figure 6. Again the departure times were allowed to "float" (no allowance for prime departure time). Marketing considerations were not primary in this scheduling exercise because it was still the objective to determine time savings potential. It was a secondary objective to attempt to determine if the size of the fleet could be reduced by increased utilization, thus reducing capital investment. This was not the case.

o TOTAL SCHEDULING EXERCISE

The final step was to schedule the 0.98 Mach aircraft on a domestic and international route network. Marketing considerations were taken into account. The higher speed aircraft on actual AA route networks, resulted in scheduling flexibility but did not reduce the number of aircraft nor did it result in additional trips. The routing charts for both a domestic and international system are contained in Figures 7 and 8. These figures compare an ATT 0.98 Mach aircraft with conventional technology aircraft and show the actual time differentials for a variety of segments. These charts may appear somewhat complicated, however, they represent actual schedules with "real world" considerations.

o COMMENT

One conclusion reached is that for a domestic network, where the average trip length is small relative to the aircraft design range, a 0.98 Mach aircraft has little advantage apart from some very slight scheduling flexibility. On selected long range segments, there is a potential advantage with the higher speed aircraft. Finally, when the aircraft

is integrated into a mix of present technology aircraft over a route system used by American Airlines, there is an advantage in scheduling flexibility but little or no change in the number of aircraft required. The utilization does not in a practical sense, appear any greater with the ATT 0.98 Mach aircraft.

o FUEL CONSUMPTION

The fuel consumption of a fleet is dependent upon the way an aircraft is used. An example of a comparison of an international and domestic operation is shown in Figure 9. To make a similar estimate for the ATT aircraft was difficult because of the lack of "off design" performance information. However, an estimate was made which is presented in Figure 10. This is an attempt to show the range in which the ATT aircraft might fall. From Figure 10, trades can be made by holding the utilization of a conventional aircraft constant while changing it for the ATT aircraft and determining the fuel consumption differences. Since the comparisons could not be rigorously prepared from ATT off-design performance data, they should be considered as boundaries rather than absolute levels. A final example of the relative fuel burn, again using ATT estimates, is shown in Figure 11.

o COMMENT

The conclusion reached is that the higher speeds are offset by greater fuel consumption. An increase in utilization also can result in higher daily consumption. If the higher speeds result in more daily trips, a figure of merit is the fuel burn per seat mile. The following index relates the relative position of the ATT aircraft with the present technology 747. Approximately, the same ranking would occur if the DC-10 were used as a base.

ATT FUEL RANKING

JFK-LAX

AIRCRAFT	SEATS	GAL/ASM	INDEX*
747-100	380	0.0173	1.00
707-300B	138	0.0272	1.57
DC-10	254	0.0168	.97
TBC 640 .90M	195	0.0171	.99
TBC 630 .95M	195	0.0180	1.04
TBC 620 .98M	195	0.0192	1.11
GD/FW .90	195	0.0125	.72
GD/FW .98	195	0.0139	.80
GLAC .95	398	0.0135	.79

* ATT/747 - GAL/ASM

Based on this comparison, there appears to be a gain in the passenger carrying fuel economy of the GDFW and GLAC aircraft when compared to the 747. The opposite is true for the TBC aircraft (with the exception of the .90M). The reason for these results is primarily (or so it would appear) decreased operating weights, although the aircraft do represent an aggregate of advanced technologies. However, as noted earlier, this is largely dependent on payload/empty weight fractions, mostly brought about by greater use of composites. If the structural payload-to-empty weight ratios developed earlier turn out to be optimistic, then the fuel ranking index will change.

o MAINTENANCE

In general, the maintenance practices anticipated for ATT will not change beyond the scope of today's system. In the past, maintenance concepts have changed to reflect better and more economical procedures. ATT airplanes should be compatible with this form of evolutionary change. The ATT study did not provide an in-depth study of maintenance practices so it was assumed that designs and materials used would be equivalent to present aircraft. There is one area of concern, however,

that requires further work by the airframe manufacturers. This area comes under the general category of systems.

The ATT aircraft may introduce control systems that, although similar to present aircraft, become critical to the operation of the aircraft. Special stability augmentation or active control systems, when made flight critical, require a different design philosophy. Back-up systems in greater depth, will be required. It was not possible from the work presented in the ATT contract studies, to render an opinion as to the adequacy of system design or maintenance requirements. It was, therefore, decided to look at present system costs and operational problems. This was done in a brief manner by utilizing American's internally generated index of system performance. The indicator is called "Quality Level Index". In substance, the QLI reflects four parameters (pilot reports, premature removals, aircraft delays and trip cancellations) which indicate sub-system and fleet performance. Only one portion of the index was used, that being the premature removals, to better reflect the costs directly related to the system. A sample of data was extracted from two general categories; Auto Flight and Navigation. The sub-systems within these categories were analyzed for the 707, 747 and DC-10 representing "past" and "present technologies". Each sub-system has a number of "sub-components" that, in aggregate, totaled 106. An indication of technology impact was considered to be the relative position of the 747 and DC-10 to the earlier developed 707 aircraft. Both cost and removal rates were traced, the results of which are shown in Figure 12.

The results reached indicate that the 747 and DC-10 had 23% and 60% percent fewer removals, respectively, for the auto-flight system. The 747 and DC-10 fleets are, however, 35% and 54% the size of

the 707 fleet, respectively. Therefore, the apparent "technology gain" is somewhat diluted. The added dimension of cost produces another measure of technology. The cost factor indicates the 747 and DC-10 to be 1.8 to 5.7 times as expensive to maintain on an hourly basis.

o COMMENT

The conclusion reached is that if additional systems are required for an ATT type aircraft, an extensive study must be performed to insure cost effectiveness.

Two of the contractor design approaches (GDFW and GLAC) had a high usage of composites. The other contractor (TBC) presented designs that contained a lesser quantity of composites emphasizing the requirement for a phased introduction for ATT aircraft (but all of the contractors recommended a phased entry of composites through various programs). The comments addressed here are reflective of the PHASE II designs. American believes that a phased introduction is the only rational way to introduce any radically new technology. In any event, there will be the necessity to establish a good foundation of experience to reveal maintenance criteria. As in metal aircraft, standards will have to be established for periodic inspections, repairs or replacements, response to cyclic loading, sonic fatigue and other resultant behavior induced from normal airline operations. To date, no extensive maintenance experience has been gained that resembles an air carrier's environment. The military has reported in a qualitative manner, that the components in service indicate that they are cost competitive with conventional structure. The data American Airlines has been able to gather only superficially substantiates an equal or lower maintenance cost. Until more experience is gained under a high utilization condition, it is impossible to predict the benefits, if any, to be gained in maintenance cost savings from the use of composites.

° NOISE

FAA is already on record as intending to lower the noise limits of FAR 36 by 10 EPNdB. Recent EPA proposals for reducing aircraft and airport noise (Federal Register, 19 February 1974; Item 6) reinforce this suggestion. The prospect of stiffer noise regulations in the not too distant future, whether in the form of the 3-point concept embodied in FAR 36, or in some other concept, is very real. Thus, the technologies which must be brought to fruition to achieve lower ATT noise levels must take account of the time period in which these airplanes might be introduced. Simply put, it seems that ATT noise reductions for the acoustic configurations given greatest emphasis by the manufacturers, corresponding to FAR 36 minus 10 EPNdB, may not be enough if they are to be introduced in a time period when other (conventional) aircraft have long since been required to conform to that criterion. ATT configurations with somewhat greater noise reductions (FAR 36 minus 15 EPNdB) were studied by the manufacturers, but not to the same extent as the "minus ten" configurations. In any event, it is not possible at this point in time to assert that minus 15 EPNdB would be a reasonable goal.

As previously reported, noise criteria should be neither unique nor preferential for any "class" of aircraft with respect to permitting it to be noisier (in airport communities) than any other class. Thus, most, if not all of the noise constraints which could affect the design and operation of ATT airplanes apply equally to other subsonic airplanes, and in particular conventional long-haul airplanes. This means that attention to power plant acoustic design features, e.g. bypass ratio, fan tip speed, fan pressure ratio, jet exhaust velocity, blade-stator spacing, etc., must receive the same attention for ATT installations as for any other type of airplane. Similarly, the effect of sound sup-

pression liners and inlet and duct splitters will have the same detrimental effects as far as airplane performance, weight, cost and operating economics are concerned.

There was found a general lack of suitability of inlet rings for noise reduction. This comes from increased risk of foreign object damage, anti-icing requirements, increased weight and probable added maintenance costs (more difficult access to the engine face, as well as maintenance of the splitters themselves).

It was not possible, in this study program, to assess the separate or cumulative effects of noise reduction design features since none of the airplane contractors submitted data on a "with-and'without" basis.

o F.A.R. AMENDMENTS

The work accomplished by American in the task of Recommendations for Amendments to Federal Aviation Regulations, addressed two aspects of the immediate advanced transport technology program. The first dealt with possible changes to the FAR's, applicable uniquely to ATT aircraft, but not to other types. In both cases, the FAR's were examined to see if specific recommendations for changes could be made, and to identify areas in the FAR's which should be the subject of further study by the NASA, FAA, or others to determine if changes are required.

The list of FAR's called out in the following discussion may not be complete. It was not possible to analyze in detail all the regulatory areas which affect the design and operation of transport category airplanes. Nevertheless, the list is considered representative of areas which should be considered candidates for study and/or possible change.

Detailed study of applicable regulations could be the subject of NASA/FAA/Manufacturer/Airline follow-on work to identify areas in need of improvement.

o CHANGES TO FAR's - Unique to ATT

A. Specific Changes

American's assessment of the design and operating characteristics of the contractors' Phase II ATT designs did not reveal characteristics which were sufficiently different from those of conventional aircraft to warrant specific recommended changes at this time.

B. Further Study Suggested

Several areas in FAR 25, "Airworthiness Standards - Transport Category Airplanes" appear to warrant further study to determine if changes uniquely applicable to ATT airplanes are in order. In some cases, changes may be dependent on the results of continued R&D on the advanced technologies themselves (e.g. strength of composite structures, etc.).

Some of the FAR's which may be unique to ATT designs and may need to be changed after more study are:

1. FAR 25.143 through FAR 25.149; "Controllability and Maneuverability."
2. FAR 25.161 "Trim."
3. FAR 25.171 through FAR 25.181 "Stability."
4. FAR 25.335(b) "design Dive Speed, V_D."
5. FAR 25.581(c) "Lightning Protection - Non-metallic Components."
6. FAR 25.867, "Fire Protection: Other Components."
7. FAR 25.631, "Bird Strike Damage."

o CHANGES TO FAR'S - NOT UNIQUE TO ATT

Several regulatory areas relating to the design, certification and operation of all CTOL transport aircraft appear to be in need of immediate improvement. However, specific changes to these FAR's will depend on further study and/or the outcome of experimental programs, some of which are known to be underway at this time.

In any event, the introduction of a new class of aircraft (e.g. ATT, SST, VTOL, etc.) particularly if it possesses unique characteristics which set it apart from its predecessors, can serve as a convenient and appropriate means of bringing about much needed improvement in some areas of the Federal Aviation Regulations as follows:

1. FAR 121.195, "Transport Category Airplanes: Turbine Engine Powered: Landing Limitations: Destination Airports."
2. FAR 121.645, "Fuel Supply: Turbine Engine Powered Airplanes, other than Turbo-Propeller: Flag and Supplemental Air Carriers and Commercial Operators."
3. Advisory Circular, AC 33-1B, dated 4-22-70, "Turbine Engine Foreign Object Ingestion and Rotor Blade Containment Type Certification Procedures."
4. FAR 36, "Noise Standards; Aircraft Type Certification."

The general conclusion is that any amendment, being suggested, would apply to the next generation aircraft whether or not it carries the label of advanced technology.

o SECONDARY POWER SYSTEM

Review of Final Report - An Advanced Concept Secondary Power System Study forAdvanced Transport Technology (Reference 7)

Four basic concepts or configurations were addressed in the

first part of the subject study:

A. Configuration I - Shaft and Bleed Power offtake from the propulsion engine which is the conventional approach.

B. Configuration II - Shaft Power Offtake only from the propulsion engine.

C. Configuration III - Dedicated APU (APU provides all power required for aircraft systems over the entire flight envelope.

D. Configuration IV - Internal Engine Generator (IEG) where all secondary power is produced by an electrical generator mounted internally within the engine.

Configuration I requires no particular comment and was adequately treated. Configuration II, however, is directed at the use of shaft power to raise fan discharge air to the required pressure for cabin pressurization. American's concerns would be with the impact of erosion, compressor efficiency achievable, etc., from such a small compressor unit, and American would undoubtedly use 707 turbo compressor experience as a starting point in any design review process. The turbo compressor which uses engine bleed air to drive a turbine of the turbo compressor unit is obviously different; but the compressor, controls, bearings and lubrication elements would be the common starting point. None of these items were particularly outstanding and in general, American's tendency would be to shy away from this type of design.

Configuration III - The concept of the dedicated APU is the most promising, provided that a completely different approach would be used in the design, installation and the development program for such a system. As noted in Section II of Reference 7, APU's are used a great deal more than would be expected (or originally intended). Their lack of reliability,

maintenance cost and high specific fuel consumption would dictate a complete study to select the cycle, design and installation features pertinent to such a system. There, of course, would be a potentially even greater payoff in STOL aircraft which for noise reasons, must be powered by higher bypass ratio (10 to 15:1) and where bleed extracted from the main engines would be even more costly (on the order of twice) in terms of impact on thrust and specific fuel consumption.

Configuration IV is not acceptable to American at this time. The cost of support of an internal engine generator (IEG), plus additional spare engines (necessitated by more frequent engine changes caused by the need for IEG removal/repair) would be quite high. The question on oil contamination and its impact on the generator performance as well as contaminations produced by a generator failure or engine failures, would be a source of real concern.

In these Boeing studies, it was assumed that equal maintenance costs would be involved on a total system basis for each configuration studied. American believes that based on the material previously discussed, this assumption was necessary in a study of this limited scope, but such would obviously not be the case in real life, and more study is obviously required.

American does agree with Boeing's preference for the dedicated APU as showing most promise. American cannot support the recommendation that all shaft power offtake is preferable over combined shaft and bleed systems without significant further study. While drag and cruise SFC are prime targets for making improvements in DOC, there appears to be greater potential for improvements if the maintenance cost impact of the various configurations were more realistically assessed.

The potential payoff from more detailed study of secondary power systems is greater perhaps than estimated by Boeing. More detailed

study of each of the systems is warranted with strong preference placed on a thorough analysis of the dedicated APU concept. Certainly the airlines are paying a high price for having APU's on board aircraft.

No fault is found with the conclusion that large potential payoffs are available from the application of advanced technology to the secondary power systems of future aircraft. More study is warranted, but such studies must be adequately funded to insure that the assumptions that are made will not erroneously impact, either positively or negatively the results of the study. The reduction of maintenance cost and cost of ownership and improved reliability are certainly equally good targets as the reduction of cruise drag and engine SFC.

It is unfortunate that the economic costing methodologies currently available do not lend themselves to this type of analysis. It is, therefore, most important that suitable economic methodologies be developed to insure an adequate assessment of the real and believed larger potential available from such advanced technology programs. In terms of priorities, American disagrees with Boeing. American believes the dedicated APU approach warrants first priority treatment. Such a unit would be the main power generating gas turbine for all secondary power requirements during the total operating flight regime.

o GENERAL ECONOMIC ASSESSMENT

The information presented by the contractors falls into a category that can be considered non-standard. This does not mean that the quality is in question. The nature of the problem to assess technology potential required a deviation from the normal material presented in a preliminary phase of development. On our part, it required an equal departure from the norm. Several avenues have been followed in an attempt to condense the information into a measure of impact to the air carrier.

A general statement that applies to all the applications of advanced technologies is they must be translated, in some manner, into a justification for investment capital. The justification has unfortunately two, altogether distinct elements. One facet is the measure of technological worth. The other is the value that must occur to make the investment worth the risk. The major thrust of the contractors was on the first. Our review will attempt to touch on both.

o MATERIALS

Application of all advanced materials, primarily composites, share the common characteristics of higher cost. They also have the same common goal of lighter weight. If the general relationship of weight and operating costs is universally representative, it would be reasonable to assume a change in one would be reflected in the other. The contractors have effected the following weight savings.

Aircraft	% Composite Used(1)	Weight Savings(2)
TBC 640	8.3(3)	10.15%
TBC 630	19.0(4)	15.25%
TBC 620		
GDFW 90M	39.0	25%
GDFW 98M	41.0	28%
GLAC 95M	60.0	38%

(1) Percent of airframe structure.
(2) Percent difference between conventional and composite aircraft.
(3) 1981 delivery date
(4) 1985 delivery date

Another way of stating the savings is that for every 10 pounds of conventional structure removed, 3.5 to 5.8 pounds of composite must be introduced.

It should be recognized that the values reflect a 1972 time frame and that a certain amount of weight reduction will occur in the normal progression of technology. Thus the weight savings would be less than above when compared to a future "conventional airplane."

Translating this into greater load carrying capability at a reduced structural weight, affects the economics of both airframe and propulsion systems. The trade to be made is the cost of the replacement material that results in the reduced weight. It is difficult to assess all the manufacturing techniques or the potential operational cost changes attributable to composite materials. The best approach that we found was to translate cost and this amount of usage into a measure of savings that must occur, to be at least equivalent with present technology equipment. This relationship is shown in Figures 13 and 14 for composites that were assumed to cost \$60/Lb and \$30/Lb (compared to aluminum @ \$1/Lb), respectively. The composite costs were deliberately assumed to be very high, in relation to aaluminum, to illustrate the sensitivity of total material costs to the price of potentially high-cost exotic materials. The point to be made is that other costs must be reduced to make the use of composites effective, economically. If less material is required or waste is reduced, this could make the advanced materials competitive. From the work contained in the ATT reviews, it is not clear that a sufficiently in-depth study has been made of this matter by the manufacturers.

If the assumption of \$1/Lb for aluminum is carried further, an estimate could be made for the cost at which composites would become equivalent. This is predicated on an estimate of only the weight of waste (raw) material in relation to the weight of a finished product.

No accounting for the effect on airplane cost of recovery/reuse of scrap material, or of differences in manufacturing costs (e.g. machine tools, forms, etc.) between aluminum and composites has been made. Ratios of the weight of raw material to finished goods, supplied by NASA, indicate value of 8:1 and 1.4:1 for aluminum and composites, respectively. If these are representative then composites would have to cost no more than $5.71/Lb to result in equal material costs, with a finished product of the same weight. If a weight savings of approximately 50% were effected, the equivalent price could increase to about $11/Lb. As stated earlier, both of these examples are referenced to a price of $1/Lb for aluminum. American Airlines is not aware of information that indicates the costs of composites will reach these levels (1972 $). Furthermore, it must be remembered that aluminum actually costs 30¢/Lb not $1/Lb, in the time frame of the economic analysis presented.

o RAW MATERIAL MARKET

o RAW MATERIAL MARKET

The market price of the raw material will have a fundamental influence on its introduction into aircraft structure. Another material, used extensively in aircrafts, was traced in its raw state to gain some insight into cost trends that could prevail for composites. Aluminum cost and production trends are shown in Figure 15. In addition to the cost of Figure 16, also shown are possible inflation influences. There are essentially two aspects that are of concern.

First, there has been a price change of about 50% in aluminum. The price, in current year dollars, reached its low point around 1945 (drop in price by about 50% since 1920), then had an approximate same order gain by 1970. There were many forces acting on the price changes during this period which brings the second aspect of concern into focus.

During the period from 1915 to 1940, the production of aluminum showed a very slight increase. From the 1940 period to present, the production rate has steadily increased. The major influence in causing the price to come down during the early years, has probably been the increased technology. If the period around 1960 is observed, it can be seen that a breakthrough in processing, drove the price down. Although inflation is a factor, it would be difficult to attach a firm quantitative value to this influence. From Figure 16, the general trend in aggregate inflation can been seen. There are so many forces acting on the economy both domestically and internationally, that it is difficult to isolate any one.

o COMMENT

If the analogy is made that any future material, such as composites, will follow similar trends, then it must be assumed that the price will fall and rise through relatively the same changes. This will probably not be the exact case. The conclusion to be reached is, that a general downward cost trend may be balanced by an opposite inflationary trend. It should be recognized that the price changes in aluminum did not occur over as short a time period as is being projected for composites (1975-1985). Even though there is an indication of lower composite costs in the near future, this optimism may be eroded by the forces at work in the general economy.

o INVESTMENT

The airplane investment as seen from the air carriers point of view is basically the flyaway price and the cost of spares. Here, only the flyaway cost is considered because every airline, depending on the size of the fleet, would require provisioning at different levels.

From the manufacturing standpoint, the cost of research and manufacturing represents the investment.

A method of looking at the relative cost of the ATT candidates was to use the number of seats being purchased as a common base. It was difficult to establish the exact list of equipment that would be considered in the flyaway price of the ATT aircraft. It was, therefore, assumed that the ATT investment would fall somewhere between the basic price and the price which includes buyer furnished equipment. This relationship is summarized in Figure 17. The manufacturing costs are listed in Table 5.

The increased speed and lower noise has resulted in a higher product cost, which was expected. An exception is found in the GDFW ATT candidates, which because of much lower R&D estimates, resulted in a relatively lower investment per seat (see Figure 17 and Table 5). If the use of composites does translate into lower R&D costs, the benefits to the air carriers are obvious. There are programs, at present, that carry a much higher R&D estimate for just engine development, which make the R&D costs appear especially low in the GDFW case. Based on present development costs, it appears that the investment for an ATT candidate is relatively greater than present technology aircraft that provide basically the same service (excluding noise). This only means that the operating cost must be lowered to make the additional investment cost effective.

o OPERATING COSTS (ATT CANDIDATES)

The direct and indirect operating costs as approached by the manufacturers (TBC, GDFW & GLAC) are primarily predicated on the price and weight of the vehicle. A direct approach to costing, such as this may appear like a simple means to circumvent a rather difficult and complex analysis. To a certain extent, the difference in operating costs that implicitly result from investment and weight changes may reflect the benefits derived from the particular technology introduced.

The formula approach to predicting costs of equipment in fleet operation today has resulted in unexplained differentials. These differences (i.e. 747 actual reported cost versus formula cost), in varying degree, result in understated costs. There may be definition problems, or the coefficients may merely reflect the time period in which the formula was based. In any case, for projecting costs, present formulas are inadequate.

The formula as discussed is based on an accurate statement of weight and price. There can be found a general relationship between these parameters and operating costs. To the extent that the relationship is linear over small ranges of either weight or price, the resultant change in operating cost can be assumed to be directly proportional to the former. This has been the implicit assumption made by the manufacturers and is the point of departure taken by American Airlines. The following is an example of differences that formulas can induce.

747 DIRECT MAINTENANCE

Example

Annual Cost Resulting From:	1972 Dollars
NASA 1970 Formula	$15,026,171
AA Formula	$17,016,836
AA Actual	$17,983,000

It can be seen that even the formula used in American Airlines' early estimates of the 747 costs did not result in exact predictions. This is merely one reason for being cautious when using a formula approach.

Using the data for both the direct (DOC) and indirect (IOC) costs, from the manufacturer without adjustment, a profit margin was established. The results are shown in Figures 19A, 19B, 19C, 20 and 21. These figures reflect, in a general manner, the potential of advanced technologies.

As mentioned previously, it is advantageous to establish a margin between the structural and volume limited payload. Figure 19A, 19B, 19C presents the reason for the margin. The greater the difference between the amount of payload required to cover costs (in this example DOC) and the "upper payload limit", either the structural or space limited weight, the more potential profit an aircraft has available. A way of presenting this margin can be in an envelope, as shown in Figure 20. In this figure, there has been introduced the element of IOC to reflect an actual profit margin. The "profit margin envelope", (expressed in the number of passenger potentially available for profit), when compared to present fleet aircraft, show gains accruing to the ATT aircraft solely due to the increased range. On average trip lengths typically experienced by American Airlines (1500-2500 KM), the DC-10 and 747 show a greater potential. To illustrate the relative profit available, a 3218 KM stage length is used strictly as an example in Figure 21. There are several significant points to be brought out which can best be made in outline form.

A. The profit potential of a 747 and DC-10 exceeds ATT candidates of similar payload and range on a 100% LF. passenger payload basis.

B. The profit potential of a 747 exceeds that of the GLAC, ATT aircraft at 50% LF., but the DC-10 has a lower or equal potential with similar ATT vehicles.

C. If the configuration of the 747 were changed to 398 seats, simulating that of the GLAC ATT aircraft, the profit potential would increase, still exceeding the ATT vehicle. (see Figure 21).

D. If the configuration of the DC-10 were changed to 195 seats, the profit potential would be lower than the similar ATT aircraft (see Figure 21).

E. If the DOC estimated by formula were optimistic by 20%, the profit potential of the 195 seat ATT candidates would be equivalent to the DC-10 with the same seating configuration.

o COMMENT

In general, the ATT vehicles in the 195 seat configuration, have better profit margins than a similar present technology aircraft with the same simulated seating, such as a DC-10. The opposite is true when comparing the 398 seat GLAC ATT aircraft with a simulated 398 seat 747. This could be interpreted as the 195 seat ATT design being competitive with present technology aircraft while the large higher seating capacity aircraft are not. This is not how American Airlines views the results. These results merely point out the need for a closer definition and projection of costs.

o TECHNOLOGY IMPACT (ATT CANDIDATES)

Using the same ground rules as in the aforementioned discussions, an operating cost benefit attributable to advanced technologies was applied to the 747 and DC-10. Those costs, within American Airlines' accounting system, that can be defined as direct, were used as a base line from which to apply the various advanced technology "cost deltas". This appeared to be a reasonable approach since detailed cost in the ATT work was not readily available in a form necessary to make an in-depth survey. The comparison is made on a TOC basis and reflects changes only in the DOC portion. All other costs (i.e. IOC) were held constant. There are certain accounts such as depreciation that would be influenced by the manufacturing cost differences discussed in the various ATT reports. The results, therefore, assume no manufacturing cost reduction or increases.

° GENERAL ECONOMIC IMPACT

Spread of Technology Impact
TOC

	¢/ASK	¢/ASM
Base Line Aircraft - DC-10	1.3560	(2.1820)
°Technology Impact Technology Impact Base Line Aircraft With:		
Supercritical Wing	1.3366-1.3388	((2.1506-2.1541)
Composite Materials	1.3300-1.3378	(2.1400-2.1526)
Active Control System	1.3426-1.3450	(2.1602-2.1654)

This summary is an example of the range of cost reductions that could occur if each technology category were implemented exclusive of the others. Again this excludes any manufacturing cost cahnge. If the total of all the technologies were applied, it is estimated that the TOC's would be reduced by about 3% to 6%. It must be emphasized that this represents a rather broad picture of range rather than exact levels. A closer review was made of one aircraft design that resulted in a more definative answer to the question of technology worth.

° TECHNOLOGY PAYOFF

A close examination has been made of selected technologies as they affect primarily a 0.90 Mach aircraft. Data were used exclusively based on the ATT studies produced by GDFW. Two additional studies (reference 5 and 6) were used to supplement the original ATT work. From these data, an impact on cost and profit accruing from advanced technologies was estimated.

The review cases that form a base from which increments in costs, attributable to selected technologies were derived, are presented in Table 7A. From the manufacturing and operating cost information, was calculated an incremental change, isolated for each of the three basic technologies, - materials, supercritical aerodynamics, and systems.

Also essential was a brief look at engine technology to complete the general review. The impact on the airframe economics is the primary goal of this contract. However, without an engine assessment, the analysis is somewhat incomplete.

All costs and investment values were placed in the 1972 time frame. This was accomplished to better reflect more current values and to compare, on a relative basis, the results with a current in-service aircraft of similar design (DC-10). A common set of assumptions were chosen for all ATT cases and the DC-10. Only the flyaway cost was considered as an investment. This eliminated any spares provisioning from the analysis. Although the DC-10 is used in a comparative manner, its use is restricted to primarily a bench mark.

A measure of an aircraft's efficiency is its contribution to the fleet mix. In some way the aircraft's profit contribution is a measure of competitive economics. The measure, however, must be subdivided into its basic elements to allow a better examination of the aggregate movement, whether it be cost or profit. It is the change in each sub-account that will be of concern in evaluating advanced technologies.

Each of the study cases were broken down into the major DOC sub-accounts defined by GDFW. The DOC for DC-10 considered the same divisions. The only point that needs reiterating is that future work will require an even more in-depth economic review, both in method and costing elements.

o COMMENT

The movement of each major cost sub-account is shown in Figures 22 thru 27. A change in DOC, accruing to a particular tech-

nology is displayed with its partitions. Each account (i.e. crew, fuel, maintenance, etc.) and its relative position with the others, can readily be seen. As previously mentioned, it was necessary to add the engines to the list of advanced technologies (this being required because of the influence on the aggregate DOC). Figures 22 and 23 show the effect of 1978 and 1982 time frame engine technology on aircraft built of aluminum or composites (40%). There is an increase in fuel consumption by as much as 8.6% (see advanced airframe materials case). Using this case as an example reveals the effective D.O.C. change. If only the advanced engines (1978 and 1982) are introduced into a (40%) composite airframe, the D.O.C. change is approximately -0.6% to 4.8%. The primary reason is noise. A goal of 10 and 15 EPNdB noise reduction from the FAR 36 level, limited the contribution of advanced engines to the overall economics. When reviewing the other figures, the engine aspects should be kept in mind. Almost in every case, the progress in advanced technologies reflects a benefit with the exception of fuel cost.

As there is a progression from the 1972 to the 1982 time frame, the fuel cost reductions become relatively less, which is a direct result of lower noise levels. If engine efficiencies were improved or the noise induced defficiency reduced, the aggregate effect on DOC becomes obvious.

A second comment is on the contribution of technologies and refers to the crew and insurance accounts. The incremental benefits shown may not occur. It is difficult to predict the crew and insurance cost of an advance technology aircraft. If it is considered a more sophisticated vehicle, the costs may be relatively more than present aircraft. Crew pay is not necessarily based only on speed and weight as some formulas might indicate. Similarly, insurance is not a direct function of the hull price.

The final comment on the DOC increments is in the airframe maintenance area. Since there are price and weight changes in the com-

parative cases, there is a resultant difference in operating costs. This difference, however, is based on a formula that may not be responsive to the underlying change. It is reconized that a change is effected by use of lighter material and that there is a cost-weight relationship. There is, however, no evidence that repair, material cost, system design etc. will actually follow the general trend, As mentioned earlier, there has been the implicit assumption that over small increments this is true. To gain a sharper perspective, maintenance costs must be analyzed in much greater depth. Maintenance, both airframe and engine, in the time period of this discussion (1972) accounted for 29% of the American Airlines operation cost. The airframe was about 50% of this amount. Without a closer definition of both airframe and engine maintenance, an investment in advanced technologies is not on a firm foundation. A summary of all the cases studied is contained in Figures 28 and 29 for a general comparison.

o PROFIT

Finally, it is necessary to translate the cost data into the profit potential. To do this, the IOC was determined, for various load factors (passenger only) and applied to the DOC. A common yield was used in all the cases from which the operating costs were taken to produce a potential profit. The relative profit margins accruing from advanced engines, materials, supercritical aerodynamics, and active control systems is presented in Figures 30 thru 33. All the study cases are summarized in Table 8. In all comparisons, the advanced technologies indicate a greater profit potential. The breakeven load factor is lower, while the margin with full passengers is higher. The DC-10, which is used as a bench mark, shows a greater margin throughout the range of L.F.'s. The breakeven load factor is 35% for the DC-10, while

it is 37% for the advanced technology aircraft. The interesting point is that this represents about 93 and 73 passenger for the DC-10 and ATT .90 Mach aircraft, respectively. In other words, the advanced technology aircraft would have a profit advantage until the upper limit of 195 seats was reached. The reason for citing this example is to point out the problem of proper sizing of an aircraft to a particular market size. If a ranking of the discussed advanced technologies were to be accomplished, it should have as an index base, a conventional, .82 Mach, 195 seat aircraft. American Airlines has estimated the characteristics of such an aircraft and established a general index of profit impact of the technology areas studied. The index, based on a scale of 4, is as follows for the airframe related elements only:

AIRFRAME	PROFIT INDEX
Composites	4.0
Supercritical Aerodynamics	3.4
Active Control System	0.6

The above represents a ranking of isolated technologies measured by profit potential, related to a 195 seat conventional .82 Mach aircraft.

o COMMENT

The conclusion reached, using exclusively the GDFW data base, is that the use of composites and supercritical aerodynamics establishes an almost equal benefit. The active control system has such a small margin, that the investment risk would probably be considered very high. One further factor must, however, be stated. All the economics discussed were devoid of full in-depth study of the detail design and maintenance aspects of the major technology areas. A potential has been shown, but the validity rests on the "cost-weight" relationship.

o POTENTIAL TECHNOLOGY IMPACT AREAS

One criticism, prevalent throughout the review of advanced technologies is the lack of attention to the basic impact areas. The economic behavior, in a gross manner, has revealed potential cost savings leading to increased profit margins. Benefits were premised primarily on weight and price change. The general theme has been the advantage of one approach or element to another. The other facet would be the standard or target that advanced technologies would be required to meet to be economically viable. A perspective should be gained into the areas in which technology will or could have a significant impact. To accomplish this, American Airlines has made an extensive as possible survey of its present fleets to determine what areas could be affected by advanced technologies. This was to serve two purposes; one to establish the areas that can be directly affected by technology advances and secondly present a relative measure of the investment worth. The second purpose is an attempt to establish the relative magnitude of the cost area to be effected by research investment. If the operating cost of some particular area (e.g. stabilizers) is relatively small when compared to other categories, it would not be prudent to expend large sums to effect a change. So to extend the ATT study, it was decided to review current fleets and determine what areas could be directly affected by advanced technology study.

First, to gain a perspective of where the operating costs go, the same base year (1972) that has been used previously was reviewed. An average was developed that combines all AA fleet type aircraft. The distribution of costs into their major categories is shown in Figure 34. Considered as a direct technology impact area is the maintenance and fuel categories which account for over 50% of all operating costs. These costs

are defined as a "potential advanced technology impact area". Within this area about 14% of the costs are directly related to airframe and systems. Fuel, engine and maintenance burden make up the remainder of the expenses. The concern in this review has been the airframe and will be focused on to investigate the potential technology impact. Along with current fleet aircraft a conventional and advanced technology study case vehicle was borrowed from the earlier discussed GDFW work (reference 6) as a bench mark.

The relative size of the airframe maintenance costs compared to the total DOC is shown in Figure 35. This summary chart places in perspective, the area which can be directly affected by design changes. Another way of viewing the operating cost is in relation to the investment. This allows for an estimate of operating costs. A ratio of cost to investment for the airframe remains within a rather narrow band for all equipment as seen in Figure 36. Figures 35 and 36 are used to illustrate the size of the airframe category in relation to the total DOC for the selected current and ATT aircraft. It should be noted that the operating cost per unit of investment (Figure 36) appears greater for the ATT aircraft, in the maintenance category, than present fleets. This emphasizes the need for a better definition of projected costs.

It would be best at this point to outline the approach that American Airlines took to place in perspective the airframe oriented operating costs. From the accounting records of the fleets of aircraft types shown in Figures 35 through 39, a sample of expense information was extracted. General expense categories were examined and classified into what was defined as "PRIMARY" and "SECONDARY" technology impact areas. It should be remembered that only the airframe associated costs

are being addressed which account for about 7.2% of all direct operational costs. The two general categories (Primary and Secondary) have eleven major expense divisions each. Within each of the eleven major divisions are hundreds of sub-accounts. Each sub-account has three elements; 1) material, 2) labor and 3) contracted services expense. The major expense divisions in the primary and secondary classifications are as follows:

POTENTIAL TECHNOLOGY IMPACT AREAS

PRIMARY	SECONDARY
Autopilot System	Inspection - Aircraft
Communications Systems	Inspection-Instrumentational, Radio & Radar
Electrical Power Systems	Turn-Around Check
Flight Control System	Termination Check
Landing Gear	Periodic Check
Navigation System	Instruments - Calibration, Oper., Accept. Check
Airborne Auxiliary Power	Warranty Credit - Aircraft
Fuselage	Air-Condition System
Nacelles & Pylons	Equipment & Furnishings
Stabilizers	Fuel System
Wings	Hydraulic Power System

The selection of the categories was based upon recurring cost or problem areas presently being experienced by current fleets and subjectively by potential problem areas that may occur from the introduction of advanced technologies. Several years of data were reviewed. However, because of time constraints, only 1972 time frame information was placed in the final form presented in this report.

As mentioned earlier, a sample of cost data was taken from the accounting records. All information will be referred to that sample with an inference to the aggregate system. Figures 37 and 38 reflect the size of the two categories. The primary categories account for about 55% to 65% percent of the material costs on established fleet types

(i.e. 707-300 and 727-200). On relatively new fleets, such as the 747 and DC-10, the range of primary costs is about 65% to 75%. The remainder of the costs are composed of the secondary and an undefined miscellaneous category. The accounts not traced that were considered miscellaneous contain such items as cabin repairs, cleaning of parts, movie system, trouble shooting, etc. These accounts could have been considered as a third category, but the task of recovering cost data was already sizable. The general hypothesis being followed is that a change made in those areas directly effected by design research (i.e. Primary technology areas) would cause a similar deviation in the secondary categories. In other words, if a better design were implemented, not only would perhaps the material or labor cost in repair be reduced, but so would the inspections, checks, calibrations, etc. Whatever is done to the primary areas will be reflected in the secondary. The purpose of the divisions is to gain some perspective into the relative magnitude of the operational costs in specific areas.

The labor "expense" was established on a "non-cost" basis. This was done to place the labor aspects on a generalized foundation. Projection can be made on a manhour basis and translated into cost with any desired labor rate. It was the intent to determine the manhours required to accomplish a task and set this as a goal to better. The relative manhours required per ramp hour for the primary category represents about 35% of the total manhours expended in the mature fleets (707 and 727). For the 747 and DC-10 this value is about 53% and 25% respectively (see Figure 38). In both the material and labor classifications, the 747 and DC-10 are probably not fully representative of a mature fleet.

On an aggregate basis the sum of <u>material</u>, <u>labor</u> and <u>contracted services</u> for the primary categories account for about 40% to 43% of the

of the direct costs. The 747 and DC-10 primary costs represent about 59% and 52% respectively. Again, the latter aircraft may not reflect a mature fleet. One very interesting observation (see Figure 39) is that if the primary costs are adjusted for the APU, the ramp hour costs in the primary category are reduced by 12% to 52%.

In each of the figures (37, 38 and 39) there is a "bench mark" that represents the sample size. This represents the sum, measured in 1972 dollars, of expenses sampled related to the total direct airframe costs on an annual basis. There is no overhead attached to any of the values discussed.

o RANKING OF POTENTIAL PRIMARY TECHNOLOGY AREAS

Taking into account the size of the sample and the preliminary nature of the study, a ranking or a relative cost impact was prepared. The ranking takes the form of relating each of the major accounts that comprise what has been defined as the primary technology area, to the sample of expenses extracted. This comparison is presented in Figure 40. As seen from this figure, the accounts form a picture of the relative impact of the selected expense categories. Where exceptions exist (immature fleets) they are noted by symbol. Making use of statistical inference it can be stated that the ranking is representative of the fleet. By making this projection from the sample to the total system of expenses, it can be argued that the sample is not fully representative. This report will not attempt to rigorously defend the stated position. There has been quantitative data presented, however, that supports and established a standard. Future studies must include a heavy emphasis on "systems" as exhibited by the first four categories shown in Figure 40. Many conclusions can be drawn from the information presented.

o COMMENT

The major conclusion is that there must be a considerable amount of study into the economic impact of advanced technologies into the sub-system levels. Only after knowledge is gained about the derivation of expenses can be meaningful change be effected.

o GENERAL COMPARISON - CONVENTIONAL AND ADVANCED TECHNOLOGY AIRCRAFT

A general review of price and cost trends of conventional aircraft was made in an attempt to correlate conventional and advanced technologies. This was accomplished to a) illustrate the foundation upon which formulas are derived and b) place a perspective on some of the dilemma imposed in assessing advanced technology benefits.

A general relationship among operating costs (DOC), flyaway price, and seats purchased is contained in Figures 41 and 42. The mean, in all cases, is biased by American Airlines' data because of knowledge of substructure composition. The flyaway price reported by other airlines is included (see Figure 41) to establish a band. This merely points up the variation in price as a result of configurations purchased. Borrowed from earlier technology payoff discussions are the conventional and advanced technology study aircraft (Cases I and D). Case D represents a full technology aircraft (1978 Engine) with the exclusion of active control systems. The performance and economic characteristics closely resemble the MACH 0.90 original GDFW ATT phase II study aircraft. Figure 43 introduces a fourth element - weight. Now there is a general relationship of DOC, flyaway price, seats, and empty operating weight (EOW). The data shown represents actual annual averages (1972) and the study cases (D & I) were based on a certain set of assumptions (see figure 7A and 7B). The DC-10 is adjusted for the same conditions. All flyaway prices were escalated to the base year (1972) by the same index (see Figure 41) for consistency.

In all instances the study Case I (conventional .82 M aircraft) does not match the established trends. As seen, the investment value and DOC appear high. Adhering to the premise that the absolute levels are not representative, but the differentials do reflect benefits, places the advanced technology vehicle into the "scatter band" of conventional aircraft prices and operating costs. There are, in fact, several conclusions that can be reached that are best stated in conjunction with the summary information presented in Figures 44, 45 and 46. The general conclusions are listed below.

(1) If the design and cost estimates for the ATT 0.90 M "full technology" aircraft are representative of a commercially saleable vehicle, then the DOC is \$40/RH greater than general trends and \$122/RH greater than a trend based on the study base assumptions (see Figure 44).

(2) If the manufacturing and operating cost differentials accruing from technology are representative, then the investment per seat is \$6,800 lower (-\$1.3 Million fly-away price) for the ATT 0.90 M aircraft and the DOC is \$100/RH less. (see Figures 44 and 45).

(3) If the manufacturing cost is absolute and the DOC differentials are representative, the net effect is a \$0.7 million dollar fly-away price <u>increase</u> and a \$87/RH <u>decrease</u> in DOC. (The \$100/RH savings is reduced by an increase in depreciation of \$13/RH. The net effect is \$87/RH). (See Figures 44 and 45.)

(4) If the relationship between the number of seats and E.O.W. is representative, then the conventional study base aircraft (CASE I) E.O.W. is too low by 12,700 KG (28,000 lb). If the operating cost differentials are again assumed representative, then an ATT 0.90 M aircraft would have an increased E.O.W. of 12,700 KG (28,222 lb) yet have a lower operating cost by about \$100/RH. (See Figures 44 and 46.)

In general, there has been found differences between trends established by historical data and projected conventional designs. This, it is believed, raises questions about the derivation of both conventional and advanced technology projections based on a formula approach. More importantly, the resultant margins in operating costs and fly-away price place the advanced technology aircraft within the boundary of present technology fleet costs. In the example used, the aggregate DOC reduction was about 9% while the fly-away price was about 11% lower for an ATT .90 M aircraft. The question that must be asked is; do these margins represent a meaningful reduction for the investment risk?

CONCLUSIONS

o ECONOMIC

1. Costing Methodology

The operating cost predictions made for the ATT aircraft were formed from derivatives of the Air Transportation Association (ATA) 1967 and the Lockheed 1970 IOC formula approach to expenses. The differences that can occur have been shown to be 20% to 30% different than actual recorded costs for equipment in present service. If these differences translate to ATT aircraft cost projections, the forecasts could be subject to major errors. It is for this reason that work must be done in the area of costing methodology to better form a foundation upon which projections can be made.

2. Design Optimization (Economic Input)

The manufacturers' approach was to maximize Return on Investment (ROI), and/or minimize operating costs in conjunction with a particular design approach. This method is, in itself, probably a good approach to designing an economically viable product. However, the foundation upon which the economics are formed is questioned. If one of the elements of cost is off by 10% or 20% and this amount is spread over the projected lifetime of the vehicle, the induced error in ROI is obvious. A design parameter optimized on ROI, that may not reflect true operating cost, will lead to misrepresented optimum designs.

3. Operating Cost Benefits

Cost reductions resulting from technology benefits were based on a formula approach. The formula has as its two major elements,

weight and price. A misquote of either element produces an erroneous absolute operating cost level. In theory, the change in operating cost, if over a small enough range, represents the "delta" expenses occuring because of the weight or price. This can only be true if the difference being reflected is a function of the two primary elements of the equation-weight and price. Although operating costs, to some degree, correlate with weight and price changes, the reflected changes have not been substantiated to a degree upon which future massive investment decisions can be based.

4. Propulsion

A closer support between the engine and airframe sides of the project would have produced a better aggregate product. The parametric sizing of engine and airframe is productive to a point. Upon arrival at a preliminary configuration, reflective of the desired end goal, an effort must be made to define closely, the engine characteristics. Without this definition, the cost aspects attributed to the propulsion sector of the aircraft economics are on a poor foundation.

The one most disturbing element attributed to the engine technology is the increase in fuel consumption. This, coupled with future fuel cost increases, places a question on advanced engine technologies. It is believed that if more effort were made in the propulsion aspects of the program, the results would have been improved.

5. Investment Risk

An investment decision is based on the best economic information

available in the time frame in which a conclusion must be reached. The judgment is not always made on exact criteria. A margin is sometimes established to reflect the risk element because the expected benefits may be somewhat lower than predicted.

The ATT economics were based on formulae that do not reflect many technical and business uncertainties that often exist during the decision making time period. For these reasons, it is subjectively concluded that a much larger margin in operating costs than was apparent from the manufacturers' ATT studies is required to offset the erosion of benefits historically encountered by the airlines.

6. General

Based on the economic analysis and reservations expressed in the preceding five conclusions, the economic benefits of advanced technologies have not been conclusively demonstrated one way or the other.

o TECHNICAL

1. 0.98 Mach Cruise

The higher speed candidates did not result in additional trips when placed in a "real network" environment, although the use of a .98 Mach cruise aircraft over a 5000 n. mi. range exclusively (i.e., every trip being long range) shows such potential. However, the present and foreseeable future networks do not reflect such an average trip length. For these reasons, the higher speed did not result in less aircraft than present fleets, or increased utilization, for the same service pattern.

2. Composite Materials

From the standpoint of profit potential, the introduction of composite materials into airframes indicated the maximum benefit. This is due primarily to the weight reductions. If the operating costs for airframes escalate without regard to weight savings beyond present levels (not reflected by the "formula" expenses), the economics will erode. This also is true for manufacturing costs.

3. Supercritical Aerodynamics

As in the composite materials case, the economic benefits primarily accrue to weight reductions. If the cost reductions are representative, then the profit potential of supercritical aerodynamics is about equal to composite materials. The ranking of benefits for all the technologies, it should be emphasized, was predicated on the potential profit impact to an air carrier.

4. Active Control Systems

The cost effectiveness of ACS was not readily apparent from the economics presented. ACS can only be considered of marginal value.

5. Subsystems

Although the ACS did not result in a significant cost change, the question of system economics was explored. From this analysis it is concluded that cost reduction must rank high in priority of research needed (see Figure 38). The methodology used by the manufacturers to assess the economics, as stated, was not considered adequate. It is concluded that benefits accruing to systems, in general, need to be explored in much greater depth.

6. Secondary Power Systems

Advanced secondary power systems indicate a potential economic benefit. The systems, in their present concept, are not of the reliability standard necessary. A dedicated secondary power system will become a flight critical item with the same reliability requirements as primary propulsion units. In the context of the ATT studies, this area warrants considerable study.

RECOMMENDATIONS

With regard to the aforementioned conclusions, the following is recommended:

1. An in-depth study of airframe and engine manufacturing methods to more closely define weight and cost benefits and trades' needs to be initiated.

2. Along with manufacturing costs, there is a need to establish in-service operating costs both for short and long range projections.

3. To establish the "real" economics of composite and supercritical aerodynamics, the technologies showing the greatest profit potential, a full scale wing should be built and flight tested on a transport category aircraft with well established baseline characteristics. Normal aerodynamic/engineering test data should be obtained. The wing should then be flown in simulated airline service (prior to certification) with a representative accumulation of flight cycles and flight hours.

4. An in-depth design and economics study is required in all systems categories to establish the value of incorporating advanced technologies in future aircraft. This study should include a complete review of the basic present and advanced design philosophy.

5. Noise being an increasing burden in future aircraft places emphasis on research into structural sound absorbing materials.

6. Along with sound absorbing materials, research should be initiated to define optimum airplane/engine configurations for noise reduction.

7. Within the framework presented in the ATT studies, the dedicated power unit concept warrants considerable design and economic review.

8. Development of hardware for the promising technologies should continue with heavy design emphasis on reliability and maintainability. All new technologies should be flown in simulated airline service, with representative accumulations of flight cycles and flight hours prior to being introduced into production aircraft.

9. When radically different (new) aircraft types such as in ATT are considered in the future, a "systems" study of integrated fleets (existing/conventional plus new types) should be made, rather than simply studying the new airplane types without regard to the mutual effects of old fleets and new fleets.

10. Future NASA airplane R&D programs involving both airframe and engine should be integrated into one program management (as the SST was done). This is essential because in actual practice it is the airframe manufacturer that will coordinate the activities associated with the efforts necessary to produce a commercially saleable product.

11. A general recommendation is that NASA should specify a uniform format for a comparative study such as the ATT. This would provide for a much more comprehensive critique in that less time is spent placing everything on a common base.

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TABLE 1

GENERAL CHARACTERISTICS

		BOEING			LOCKHEED-GEORGIA	GENERAL DYNAMICS - FORT WORTH	
		767-640	767-630	767-620	GLAC-95	G/D-98	G/D-90
CRUISE MACH		.90	.95	.98	.95	.98	.90
ENGINES (Number)		ATSA 4-2800-24(3)	ATSA 4-2800-24(3)	ATSA 4-2800-24(3)	P&W STF-429(4)	P&W STF-429(3)	P&W STF-429(3)
THRUST	KG(lb)	14200 (31300)	15560 (34300)	17600 (38800)	20412 (45000)	12011 (26480)	10160 (22400)
LENGTH (Overall)	M (ft)	53.77 (176.4)	55.95 (183.6)	59.18 (194.2)	79.86 (262.0)	59.0 (193.58)	52.48 (172.16)
HEIGHT (Overall)	M (ft)	13.21 (43.3)	13.41 (44.0)	13.34 (43.7)	18.99 (62.3)	15.58 (51.1)	14.50 (47.58)
SPAN	M (ft)	40.23 (132.0)	38.96 (127.8)	39.52 (129.7)	58.15 (190.79)	43.21 (141.75)	42.62 (139.83)
WING AREA	$M^2(ft^2)$	210.0 (2260)	227.6 (2450)	249.9 (2690)	444.0 (4764.3)	212.0 (2282)	183.0 (1970)
WING SWEEP DEG/%C		36.5°/.25C	40°/.25C	42.2/.25C	38.7°/.25C	40°/.50C	36°/.50C
ASPECT RATIO		7.6	6.9	6.4	7.64	8.0	9.0
WHEEL TREAD	M (ft)	7.12 (28.3)	7.12 (28.3)	7.12 (28.3)	(40.0)	9.91 (32.5)	9.04 (29.665)
WHEEL BASE	M (ft)	17.86 (58.6)	18.47 (60.6)	18.95 (62.2)	(96.7)	21.27 (69.375)	20.96 (68.75)
MAX CONTAINERIZED VOLUME	$M^3(ft^3)$	44.09 (1557)	57.59 (2034)	57.59 (2034)	128.59 (4543)	35.8 (1264)	107.4 (3792)
BULK CARGO VOLUME	$M^3(ft^3)$	22.65 (800)	14.16 (500)	14.16 (500)	19.82 (700)	93.4 (3297)	34.5 (1219)
FUEL CAPACITY 803 KG/M^3 6.7 lb/gal	KG(lb)	41142 (90700)	45814 (101000)	49261 (108600)	142101 (313275)	49330 (108752)	44764 (98687)
MAX T.O.G.W.	KG(lb)	137760 (303700)	145150 (320000)	154490 (340600)	290000 (640000)	124214 (273840)	112214 (247432)
MAX LNDG WT	KG(lb)	117029 (258000)	123379 (272000)	131317 (289500)	221357 (488000)	104339 (230025)	94276 (207840)
MAX Z.F.G.W.	KG(lb)	97524 (215000)	100246 (221000)	106142 (234000)	166562 (367176)	83504 (184128)	76160 (167935)
MAX STRUC PL	KG(lb)	25124 (55450)	22476 (49710)	22302 (49160)	38476 (84800)	18140 (40000)	18140 (40000) 1/
*MAX SPACE LIMIT PL	KG(lb)	25805 (56890)	26761 (59000)	26838 (59170)	54472 (120090)	35727 (78760)	37770 (83260)
O.W.E.	KG(lb)	72370 (159550)	77770 (171290)	83840 (184840)	128086 (282376)	65376 (144128)	58031 (127935)
PAX - %FC/%C		196-15/85	198-15/85	199-15/85	398-10/90	195-15/85	195-15/85
ATTENDANTS		6	6	6	10	6	6
LAVATORIES		6	6	6	10	6	6
FWD CABIN SEATS		29	30	30	40	30	30
FWD CABIN PITCH	CM(in)	96 (38)	96 (38)	96 (38)	96 (38)	96 (38)	96 (38)
AFT CABIN SEATS		167	168	169	358	165	165
AFT CABIN PITCH	CM(in)	86 (34)	86 (34)	86 (34)	86 (34)	86 (34)	86 (34)
PAX 77.11 KG/Pax (170 lb/Pax)		15114 (33320)	15268 (33660)	15345 (33830)	30691 (67660)	15037 (33150)	15037 (33150)
BAGGAGE 13.61 KG/Pax (30 lb/Pax)		2668 (5880)	2694 (5940)	2708 (5970)	5416 (11940)	2653 (5850)	2653 (5850)
CONTAINERIZED CARGO 160.19 KG/M^3 (10 lb/ft^3)		4395 (9690)	6531 (14400)	6517 (14370)	15191 (33490)	3082 (6790)	14551 (32070)
BULK CARGO 160.19 KG/M^3 (10 lb/ft^3)		3628 (8000)	2268 (5000)	2268 (5000)	3175 (7000)	14955 (32970)	5529 (12190)
*SPACE LIMIT PL	KG(lb)	25805 (56890)	26761 (59000)	26838 (59170)	54472 (120090)	35727 (78760)	37770 (83260)
JTV/fm 8-8-73							

1/ Assumed 27216 Kg (60,000 lb.) for M.Z.F.G.W., as well as 40,000 lb. to account for 1.5 design factor stated by manufacturer.

TABLE 2

BELLY CARGO AND BAGGAGE DENSITY AVAILABLE
FOR WEIGHT LIMITED PAYLOAD

(100% PAX LOAD)

ATT Aircraft		Containers & Bulk (1) Kg/M^3	(Lb/Ft^3)	Cargo Containers & Bulk (2) Kg/M^3 **	(Lb/Ft^3)	Cargo Containers Only (3) Kg/M^3 **	(Lb/Ft^3)
Boeing	.90M	150.6	(9.4)	147.4	(9.2)	269.1	(16.8)
"	.95M	100.9	(6.3)	83.3	(5.2)	112.1	(7.0)
"	.98M	96.1	(6.0)	76.9	(4.8)	104.1	(6.5)
GD	.90M	22.4	(1.4)	3.2	(0.2)	4.8	(0.3)
"	.98M	24.0	(1.5)	4.8	(0.3)	24.0	(1.5)
GLAC	.95M	52.9	(3.3)	20.8	(1.3)	25.6	(1.6)
GD *	.90M	86.5	(5.4)	75.3	(4.7)	104.1	(6.5)
GD *	.98M	94.5	(5.9)	84.9	(5.3)	495.0	(30.9)

* Assumed weight limit payload = 60,000 Lb.

Conventional (Current) Aircraft	Containers & Bulk (1) Kg/M^3	(Lb/Ft^3)	Cargo Containers & Bulk (2) Kg/M^3	(Lb/Ft^3)	Cargo Containers Only (3) Kg/M^3	(Lb/Ft^3)
B-747-123	411.7	(25.7)	517.4	(32.3)	820.2	(51.2)
DC-10-10	157.0	(9.8)	155.4	(9.7)	243.5	(15.2)
DC-10-30	371.7	(23.2)	442.2	(27.6)	688.9	(43.0)
B-707-323B	272.3	(17.0)	333.2	(20.8)	NA	(NA)
CV990A	382.9	(23.9)	539.9	(33.7)	NA	(NA)

- o Structural Payload = WLPL
- o Number Pax = N
- o Psgr. Payload = Wp = 77N Kg (170N Lb)
- o Baggage Load = Wb = 14N Kg (30N Lb) @ 160 Kg/M^3 (10 Lb/Ft^3)
- o Cargo & Baggage Density = p
- o Container Volume (Baggage) = Vbg
- o Container Volume (Cargo) = Vcx
- o Bulk Volume (Cargo) = Vbk

(1) $$P = \frac{WLPL - N}{Vbg + Vcx + Vbr}$$ (Average Density, Baggage & Cargo)

(2) $$Pcx = \frac{WLPL - (Wp + Wb)}{Vcx + Vbk}$$

(3) $$Pcx = \frac{WLPL - (Wp + Wb)}{Vcx}$$

** Actual available cargo densities would be slightly more than shown above because cargo would not be loaded in a baggage container that was not full.

TABLE 3

WEIGHT GROWTH HISTORY

	In Service Date	EOW (LB) 1960	EOW (LB) 1965	EOW (LB) 1968	EOW (LB) 1972	Net Chg. (LB)	MZFGW (LB)
707-123/123B	1/25/59	118940	126967	132751	132592	13652	170000
720-023/023B	7/23/60	110673	117387	119620	122541**	11868	147000
CV990A	3/18/62	119774*	120285	122448	--	2674	160000
727-223	3/4/68	--	--	101512	101643	131	136000***

	Full Pax Payload (LB)	Space Limit Payload (LB)	Structural Payload (LB) Initial	Structural Payload (LB) 1972	Margin (LB) Initial	Margin (LB) 1972
707-123/123B	23800	36910	51060	37408	14150	498
720-023/023B	21000	31650	36327	24459	4677	(7191)
CV990A	20800	26010	40226	37552	14216	11542
727-223	24600	32790	34488	34357	1698	1567

* 1962

** 1971

*** Operational Conversion

9/73

TABLE 4

SPEED CHARACTERISTICS

	Cruise Mach No. (Entry Into Service)	Cruise Mach No. (1973) *	Mmo	M_D
Current Aircraft				
747-100	.86 **	.84	.92	.97
DC-10-10	.85 **	.83	.88	.95
707-323B/C	.82	.82	.90	.95
727-223	.85	.82	.90	.95
707-123B	.85	.82	.90	.95
ATT Aircraft				***
Boeing - .90		.90		.95
Boeing - .95		.95		1.00
Boeing - .98		.98		1.03
GDFW - .90		.90		0.95
GDFW - .98		.98		1.03
GLAC - .95		.95		1.00

* Further reductions may be scheduled as a result of fuel conservation program.
** Original Plans, Not Used

*** Minimum Required M_D, Based On FAR 25.335

TABLE 5

Investment
(1970 $)

Development Costs

	R&D(3) (000,000)
TBC 640	500.256
630	554.700
620	601.829
GDFW 98	387.100
90	330.760
GLAC 95	750.448

Unit Cost $ (000,000)

	200 Aircraft			400 Aircraft		
	R&D(3)	Mfg.(2)	Total(1)	R&D(3)	Mfg.(2)	Total(1)
TBC 640(4)	$2.501	$11.828	$14.326	$1.251	$10.374	$11.625
630	2.773	12.884	15.657	1.387	11.269	12.656
620	3.009	13.843	16.852	1.504	12.089	13.593
GDFW 90(5)	1.654	11.306	12.960	0.827	10.133	10.960
98	1.935	12.264	14.200	0.968	11.232	12.200
GLAC 95(6)	3.752	29.877	33.629	1.876	25.150	27.026

(1) No profit.
(2) Includes engine.
(3) R&D Airframe only.
(4) Note Schedule A
(5) Note Schedule B
(6) Note Schedule C

SCHEDULE A-1

TBC 1970 $ (000,000)

	TBC-640	TBC-630	TBC-620
Non-Recurring	$500.256	$554.700	$601.829
Airframe Cost $/Aircraft			
200 Units	$12.341	$13.540	$14.559(2)
400	9.640	10.539	11.300
Engine(3)	1.985	2.117	2.293(1)
Total Aircraft Cost			
200 Units	14.326	15.657	16.852(3)
400	11.625	12.656	13.593
Non-Recurring $/Aircraft			
200 Units	2.501	2.773	3.009
400	1.251	1.387	1.504
Manufacturing Cost $/Aircraft(4)			
200 Units	11.828	12.884	13.843
400	10.374	11.269	12.089

For 1972 $ escalate per --
(1) 1972 $ 10.2% escalation
(2) " 8.0% "
(3) " 8.3% "
(4) Includes engine.

SCHEDULE B-1

- GDFW $ (000,000) (1970 $)

			GDFW 90	GDFW 98
R&D (exc. tooling)			$235.460	$279.700
Tooling			95.300	107.400
Total R&D (non-recurring)			$330.760	$387.100
.98 Aircraft Price[1]	200 Units	@ $14.2		2840.00
(P.124, Vol. I)	400 "	@ 12.2		4880.00
(P.115, Vol. I)	250 "	@ 13.33		3333.49
.90 Aircraft P.118	250 Units	@ $12.09	3022.10	
Assume Same (2)	200 "	@ 12.96	2592.00	
as .98 Aircraft	400 "	@ 10.96	4384.00	
Manufacturing & Support Cost				
200 Aircraft			2261.24	2452.90
250			2691.34	2946.39
400			4053.24	4492.90
Manufacturing Cost/Aircraft[1]				
200 units ($ M)			11.306	12.264
250			10.765	11.785
400			10.133	11.232
R&D Write-Off/Aircraft				
200			1.654	1.935
250			1.323	1.548
400			0.827	0.968

(1) Includes engine.
(2) Assumes same distribution of costs

SCHEDULE C-1

GLAC 95 (1970 $) (000,000)

	Unit Cost	$/Aircraft		
UNITS	200	400	567	800
Production Cost	29.877	25.150	22.475	20.251
Write-Off R&D	3.752 (1)	1.876	1.330	0.938
Total Production Cost	33.629	27.026	23.805	21.189
Profit	4.371	3.513	3.095	2.755
Aircraft Price	38.000	30.539	26.900	23.944
% Profit (i.e. of price)	11.503 (2)	11.503	11.50558	11.506
% Profit (i.e. of cost)		12.9986	13.0015	13.002

(1) $750.448 (M)

(2) Assumed and applied to $38M for profit.

TABLE 6

PROFIT POTENTIAL (at Maximum Passenger Payload)

2000 St. Mi. Segment ⟶ 126.48 $/Passenger @ 6.324¢ Yield

• Maximum Potential

	Pax(1)	Pax(2)	Profit $(1)	Profit $(2)	(1)	(2)
					(DC10-ATT)	
TBC 640	151	152	19098	17960	$2656	$3668
630	153		19351		2277	
620	151		19098		2530	
GDFW 90	142	131	17960	16569	3668	5059
98	142		17960		3668	
					(747-ATT)	
GLAC 95	236	204	29849	25802	2909	6956
DC10	171		21628			
747	259		32758			

(1) Derived from costs as represented by the manufacturer.
(2) D.O.C. adjusted by 20% to simulate the difference between formula and actual costs.

• 50% L.F.

	Pax(1)	Pax(2)	Profit $(1)	Profit $(2)	(1)	(2)
TBC 640	53	41	6703	5186	$(1138)	$379
630	↓	↓	↓			
620						
GDFW 90	45	34	5692	4300	(127)	1265
98	↓	↓				
GLAC 95	30	5	3794	632	4933	8095
DC10	44		5565			
747	69		8727			

Simulated ATT Configuration for 747 and DC10

• Maximum Potential

DC10	132	16695	(195 Seats)
747	271	34276	(398 Seats)

• 50% L.F.

DC10	35	4427	(195 Seats)
747	72	9106	(398 Seats)

TABLE 7A

TECHNOLOGY REVIEW CASES

CASE	NOISE LEVEL	MACH	AIRFRAME	ENGINE
A	FAR 36	0.90	ALUM. + S/C	JT9D
B	FAR 36	.90	G/E + S/C	JT9D
C	FAR 36-10	.90	ALUM. + S/C	STF429
D	FAR 36-10	.90	G/E + S/C	STF429
E	FAR 36-15	.90	ALUM. + S/C	STF433
F	FAR 36-15	.90	G/E + S/C	STF433
G	FAR 36-15	.90	ALUM + S/C + ACS	STF433
H	FAR 36-15	.90	G/E + S/C + ACS	STF433
I	FAR 36	.82	ALUM.	JT9D
J	FAR 36	.85	ALUM. + S/C	JT9D
DC-10-10	FAR 36	.83	ALUM.	CF6

Economic Study Assumptions

Average trip length 1000 mi. (1150 St.Mi.)
Annual utilization 3650 Ramp hours
No spares investment
Cost and revenue were escalated to 1972 $

TABLE 7B

STUDY INVESTMENT BASE

(1972 $) [1]

CASE	ATT STUDY CASES AIRFRAME & SYSTEMS	FLYAWAY PRICE
A	$10,808,390	$13,926,447
B	9,962,434	12,920,002
C	10,698,934	13,834,762
D	9,820,131	12,790,079
E	10,415,232	13,133,573
F	9,533,962	12,087,374
G	10,317,493	13,004,112
H	9,382,572	11,931,549
I	10,983,128	14,114,818
J	10,519,691	13,486,433

	PRESENT TECHNOLOGY AIRCRAFT AIRFRAME & SYSTEMS	FLYAWAY PRICE
DC-10-10	$14,773,000	$17,082,000

1 INVESTMENT ESCALATED FROM BASE YEAR BY: IMPLICIT PRICE DEFLATOR FOR PRIVATE PURCHASES OR PRODUCERS' DURABLE EQUIPMENT. AIRCRAFT INDEX; SOURCE: SURVEY OF CURRENT BUSINESS JULY,'70, '71, '72, and '73.

TABLE 8

SUMMARY
POTENTIAL PROFIT MARGIN FROM SELECTED
ADVANCED TECHNOLOGIES
(1972 $)

PSGR. YIELD - 6.3659¢ /RPM

STUDY CASE	Δ ¢/RPM								
	30% LF	40% LF	50% LF	60% LF	70% LF	80% LF	90% LF	100% LF	BE.LF
Rev. Psgr. ATT	59	78	98	117	137	156	178	195	
Rev. Psgr. DC-10	76	102	127	152	178	203	229	254	
A. 0.90M - S/C ALUM JT9D	(2.6387)	(0.5951)	0.6899	1.5263	2.1215	2.5673	2.9147	3.1925	43.7
B. 0.90M - S/C G/E JT9D	(1.9591)	(0.0333)	1.1183	1.8916	2.4419	2.8541	3.1752	3.4320	40.0
C. 0.90M - S/C ALUM STF429	(2.6974)	(.6008)	.6531	1.4949	2.0941	2.5423	2.8923	3.1719	44.2
D. 0.90M - S/C G/E STF429	(2.0144)	(.0758)	1.0835	1,7398	2,4158	2.8307	3.1539	3.4125	40.3
E. 0.90M - S/C ALUM STF433	(2.2214)	(.2341)	.9531	1.7506	2.3184	2.7434	3.0747	3.3396	41.7
F. 0.90M - S/C G/E STF433	(1.5347	.2757	1.3719	2.1078	2.6315	3.0237	3.3293	3.5738	38.2
G. 0.90M - S/C ACS ALUM STF433	(2.1041)	(.1446)	1.0271	1.8138	2.3737	2.7929	3.1197	3.3810	40.8
H. 0.90M - S/C ACS ALUM STF433	(1.4681)	.3439	1.4279	2.1554	2.6734	3.0612	3.3634	3.6051	37.5
I. 0.82M - ALUM JT9D	(3.2801)	(1.0486)	.2859	1.1818	1.8194	2.2969	2.6689	2.9666	47.5
J. 0.85M - S/C ALUM JT9D	(2.6737)	(.5828)	.6679	1.5074	2.1051	2.5526	2.9013	3.1802	43.7
DC-10-10	(0.9111)	0.7724	1.7791	2.4549	2.9361	3.2962	3.5769	3.8014	35.0

TABLE 9

OPERATION COST SUMMARY

Total Fleet

(Direct Labor, Material, and Contracted Services)

1972

	707-323B	707-323CC	727-200	747-123	DC-10-10
AIRFRAME AND OTHER FLIGHT EQUIPMENT: (Direct Only)					
\$/RH	54.81	52.23	49.24	143.03	75.33
¢/ASM	0.0981	0.0944	0.1153	0.1034	0.0835
¢/ATM	0.6155	0.7260	0.8635	0.6310	0.5595
D.O.C. (Including Maintenance Overhead):					
\$/RH	904.82	898.20	711.75	1929.97	1316.19
D.O.C. (Excluding Depreciation & Rental):					
\$/RH	706.48	693.69	564.92	1246.16	906.58
MAINTENANCE COST (Including Overhead):					
\$/RH	206.04	232.85	207.66	527.52	355.50

TABLE 10
COST PER $ INVESTMENT

ASSUMPTION:
AVERAGE TRIP LENGTH, 1150 ST. MI.
UTILIZATION 3650 RH/YR
AVERAGE TRIP RAMP TIME 2.75 HR (.82 M A/C)

1972

	707-323B	707-323CC	727-200	747-123	DC-10-10
Number of Seats	138	138	124	380	254
AIRFRAME & OTHER FLIGHT EQUIPMENT (Direct Only)					
10 RH/DAY UTILIZATION					
$/RH (3650 RH/YR)	$200056	$190639	$179726	$522059	$274954
DOC/$ INVEST(2)	0.02559	0.02438	0.03188	0.02588	0.01861(1)
$ INVEST(2)/SEAT	56658	56658	45675	53078	58161
DOC					
$/RH (3650)	$3302593	$3278430	$2597887	$7044390	$4804093
DOC/$ INVEST(2)	0.4224	0.4193	0.4609	0.3492	0.3252
DOC/A/C INVEST(3)	0.3640	0.3614	0.3924	0.2984	0.2812
CASH EXPENSES					
$/RH (3650)	$2578652	$2531968	$2061958	$4548484	$3309017
DOC/$ INVEST(2)	0.3298	0.3238	0.3658	0.2255	0.2240
DOC/$ A/C(3)	.2842	0.2791	0.3114	0.1929	0.1937
MAINTENANCE (Including Overhaul)					
$/RH (3650)	$ 752046	$ 849902	$ 757959	$1925448	$1297575
DOC/$ INVEST(2)	0.0962	0.1087	0.1345	0.0955	0.0878
DOC/$ A/C INVEST(3)	0.0829	0.0937	0.1145	0.0816	0.0759

(1) First Three Quarters of 1973 indicates this value will be approximately 0.02835.

(2) Investment - Airframe and Systems only.

(3) Investment - Aircraft including Engines.

TABLE 11
MATERIAL COST SUMMARY

(AIRFRAME AND OTHER FLIGHT EQUIPMENT)
1972

	FLEET AVERAGE	707-323B	707-323CC	727-200	747-123	DC-10-10
AIRFRAME						
$/RH	19.15	18.33	11.95	14.90	45.42	27.66
¢/ASM	0.038	0.026	0.022	0.035	0.033	0.030
¢/ATM	0.228	0.188	0.173	0.263	0.199	0.203
OTHER FLIGHT EQUIPMENT						
$/RH	3.04	4.61	3.41	2.63	4.62	3.03
¢/ASM	0.006	0.007	0.006	0.006	0.003	0.003
¢/ATM	0.036	0.047	0.049	0.046	0.020	0.022
TOTAL						
$/RH	22.15	22.94	15.36	17.53	50.04	30.69
¢/ASM	0.044	0.033	0.028	0.035	0.036	0.033
¢/ATM	0.264	0.235	0.222	0.309	0.219	0.225

TABLE 12

MATERIAL COST SUMMARY
SUBSYSTEM SAMPLE
(AIRFRAME AND OTHER FLIGHT EQUIPMENT)

1972

	707-323B	707-323CC	727-200	747-123	DC-10-10
SAMPLE					
$/RH	9.91	11.62	13.86	20.00	15.51
¢/ASM	.01575	.02059	.03256	.01445	.01719
¢/ATM	.11134	.15842	.24306	.08823	.11521
PRIMARY TECHNOLOGY CATEGORY					
$/RH	6.44	7.45	7.82	12.83	11.84
¢/ASM	.01023	.01320	.01832	.00927	.01313
¢/ATM	.07233	.010161	.13720	.05660	.08800
SECONDARY TECHNOLOGY CATEGORY					
$/RH	2.45	2.74	2.10	2.35	1.05
¢/ASM	.00388	.00486	.00491	.00169	.00116
¢/ATM	.02748	.03742	.03677	.01035	.00780
MAJOR TECHNOLOGY CATEGORY					
$/RH	8.89	10.19	9.92	15.18	12.89
¢/ASM	.01411	.01806	.02323	.01096	.01429
¢/ATM	.09981	.13903	.17397	.06696	.09580
PRIMARY AS % SAMPLE	64.97%	64.14%	56.45%	64.15%	76.38%
SECONDARY " " "	24.68	23.62	15.13	11.74	6.78
MAJOR " " "	89.65	87.76	71.58	75.89	83.16
SAMPLE AS % FLEET COST	43.19%	75.65%	79.06%	39.96%	50.53%

TABLE 13
LABOR REQUIREMENT SUMMARY

(AIRFRAME AND OTHER FLIGHT EQUIPMENT)

1972

	707-323B	707-323CC	747-200	747-123	DC-10-10
SUBSYSTEM SAMPLE					
	M/H/RH				
SAMPLE	2.22	2.86	2.86	1.20	2.22
PRIMARY TECH. CATEGORY	0.83	1.06	1.00	0.64	0.57
SECONDARY TECH. CATEGORY	0.79	0.95	0.96	0.48	0.63
TOTAL MAJOR CATEGORY	1.62	2.01	1.96	1.12	1.20
	M/H/ASM				
SAMPLE					
PRIMARY TECH. CATEGORY	35.0	50.1	67.2	8.6	24.6
SECONDARY TECH. CATEGORY	13.0	18.8	23.5	4.6	6.2
TOTAL MAJOR CATEGORY	13.0	16.9	22.5	3.5	6.9
	M/H/ATM				
SAMPLE	248.0	386.0	505.0	53.0	165.0
PRIMARY TECH. CATEGORY	93.0	145.0	176.0	28.2	42.1
SECONDARY TECH. CATEGORY	89.0	130.0	168.9	21.2	46.7
TOTAL MAJOR CATEGORY	182.0	275.0	344.9	49.4	88.8
PRIMARY AS % SAMPLE	37.4%	37.1%	35.0%	53.3%	25.7%
SECONDARY AS % SAMPLE	35.6	33.2	35.6	40.0	28.4
MAJOR CAT. AS % SAMPLE	73.0	70.3	68.6	93.3	54.1
SAMPLE AS % FLEET	57.7%	62.9%	65.7%	14.4%	42.2%
FLEET MAINTENANCE					
MH/RH	3.85	4.55	4.35	8.33	5.26 1/
MH/ASM	61.2	82.2	102.2	58.0	58.0
MH/ATM	432.3	632.0	763.3	353.4	390.6

1/ Includes Warranty Labor Credits - Projected for 8 MH/RH on a Mature Fleet

TABLE 14
AIRFRAME MAINTENANCE COST SUMMARY
SUBSYSTEM SAMPLE
(DIRECT LABOR, MATERIAL, AND CONTRACTED SERVICES)
1972

	707-323B	707-323CC	727-200	747-123	DC-10-10
SAMPLE					
$/RH	32.25	35.99	35.67	66.71	39.33
¢/ASM	0.0512	0.0638	0.0835	0.0482	0.0435
¢/ATM	0.3621	0.4909	0.6255	0.2943	0.2921
PRIMARY TECHNOLOGY CATEGORY					
$/RH	12.78	15.39	16.04	39.09	20.61
¢/ASM	0.0203	0.0273	0.0375	0.0282	0.0228
¢/ATM	0.1436	0.2097	0.2812	0.1724	0.1531
SECONDARY TECHNOLOGY CATEGORY					
$/RH	8.63	10.01	9.12	13.92	6.86
¢/ASM	0.0137	0.0177	0.0213	0.0100	0.0076
¢/ATM	0.0969	0.1365	0.1598	0.0614	0.0510
MAJOR TECHNOLOGY CATEGORY (PRIMARY & SECONDARY)					
$/RH	21.41	25.40	25.16	53.01	27.47
¢/ASM	0.0340	0.0450	0.0588	0.0382	0.0304
¢/ATM	0.2405	0.3462	0.4410	0.2338	0.2041
PRIMARY AS % SAMPLE	39.64%	42.75%	44.98%	58.59%	52.41%
SECONDARY AS % SAMPLE	26.76	27.81	25.56	20.86	17.45
MAJOR AS % SAMPLE	66.40	70.56	70.54	79.45	69.86
SAMPE AS % FLEET	58.83	67.61	72.44	46.63	52.00
ADJUSTED FOR APU					
SAMPLE $/RH			33.80	49.36	28.35
PRIMARY TECH. CAT. $/RH			14.18	21.74	9.63

TABLE 15
POTENTIAL ADVANCED TECHNOLOGY STUDY AREAS

SUBSYSTEM SAMPLE
(AIRFRAME COSTS AS PERCENT OF SAMPLE)
1972

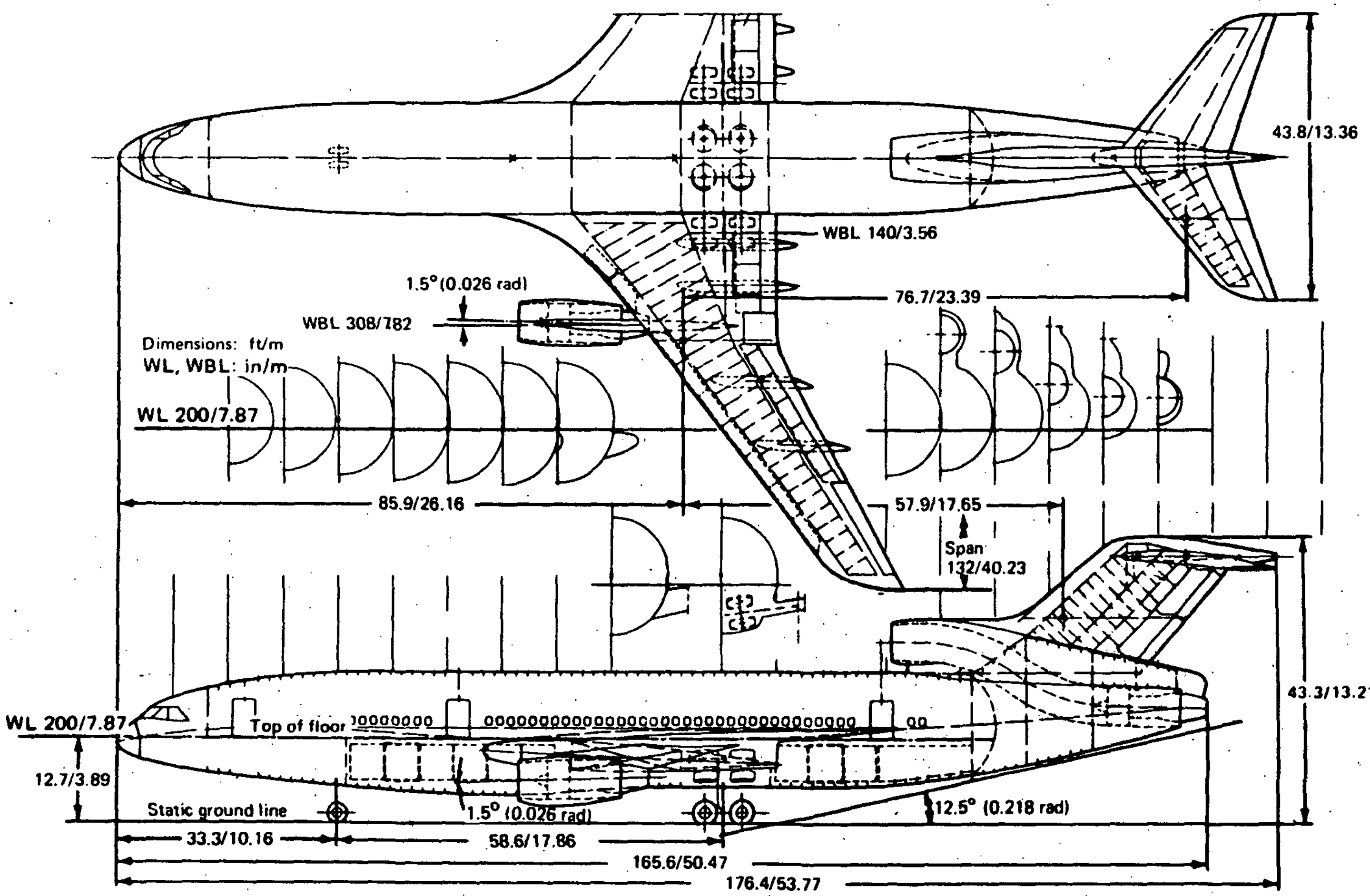
CATEGORY	707-323B	707-323CC	727-200	747-100	DC-10-10 (2)
PRIMARY TECHNOLOGY CATEGORIES					
AUTO FLIGHT	2.09%	1.84%	1.59%	1.77%	1.54%
ELECTRICAL POWER	4.61	4.73	3.17	1.38	3.39
FLIGHT CONTROL	5.13	5.84	6.64	4.15	1.76
NAVIGATION	6.05	5.26	2.91 (3)	5.93	5.45
AUXILIARY POWER	-NA-	-NA-	5.24	26.01	27.92
COMMUNICATION	0.46	0.74	0.36	3.49	0.39
FUSELAGE	0.75	1.82	2.87	0.08	0.88
NACELLES & PYLONS	0.23	0.75	0.50	0.39	1.01
STABILIZERS	0.48	0.66	0.70	(1)	0.13
WINGS	1.40	2.98	2.07	3.78	0.73
LANDING GEAR	18.41	18.19	18.93	11.63	9.20
PRIMARY AS % SAMPLE	39.64%	42.75%	44.98%	58.59%	52.41%
SECONDARY AS % SAMPLE	26.76	27.81	25.56	20.86	17.45
MAJOR AS % SAMPLE	66.40	70.56	70.54	79.45	69.86
SAMPLE AS % TOTAL FLEET	58.83	67.61	72.44	46.63	52.00

(1) NEGLIGIBLE AMOUNT

(2) DOES NOT REFLECT A MATURE FLEET

(3) NO INERTIA NAVIGATION SYSTEM

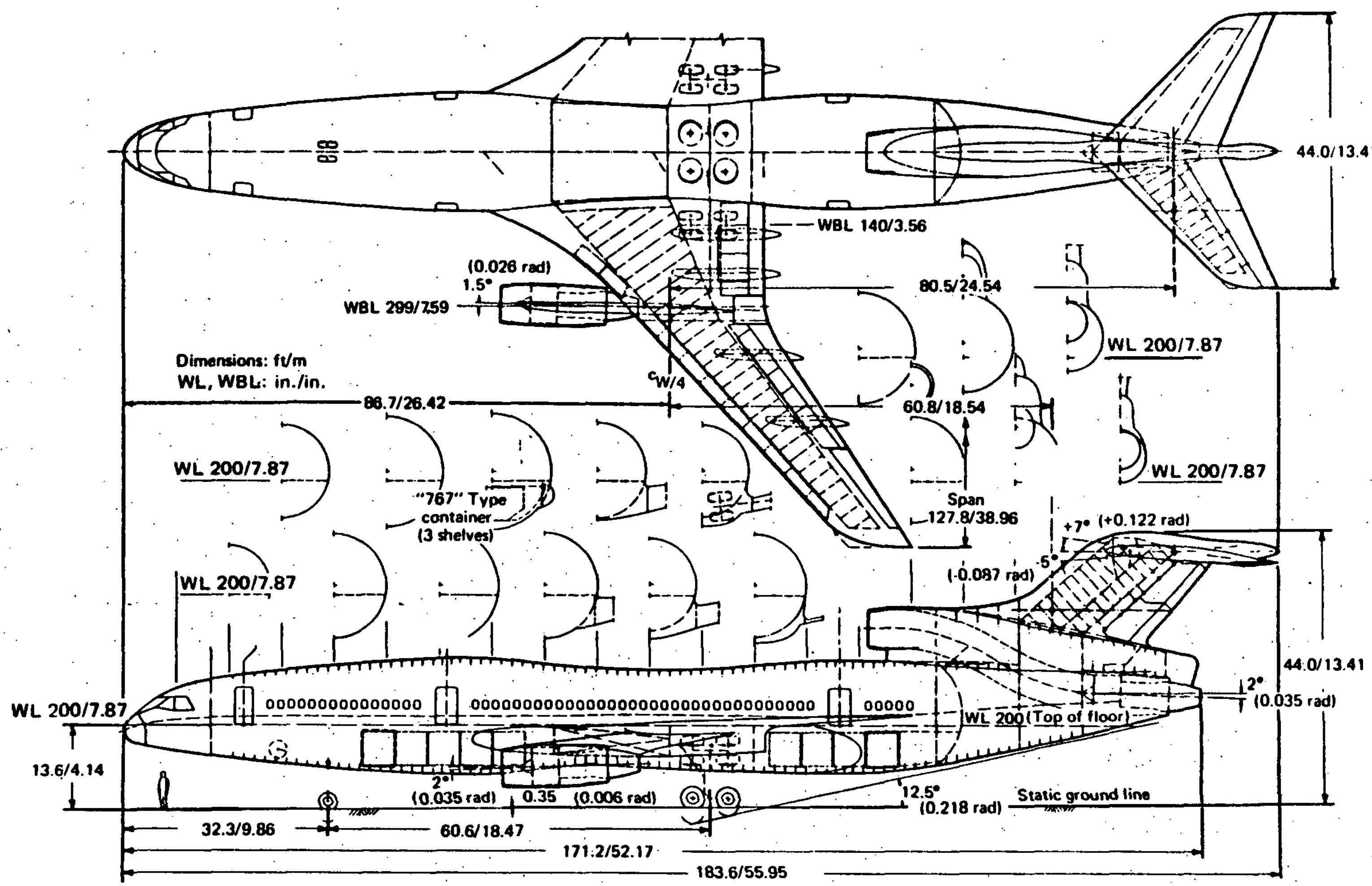
FIGURE 1A



General arrangement

TBC - 640

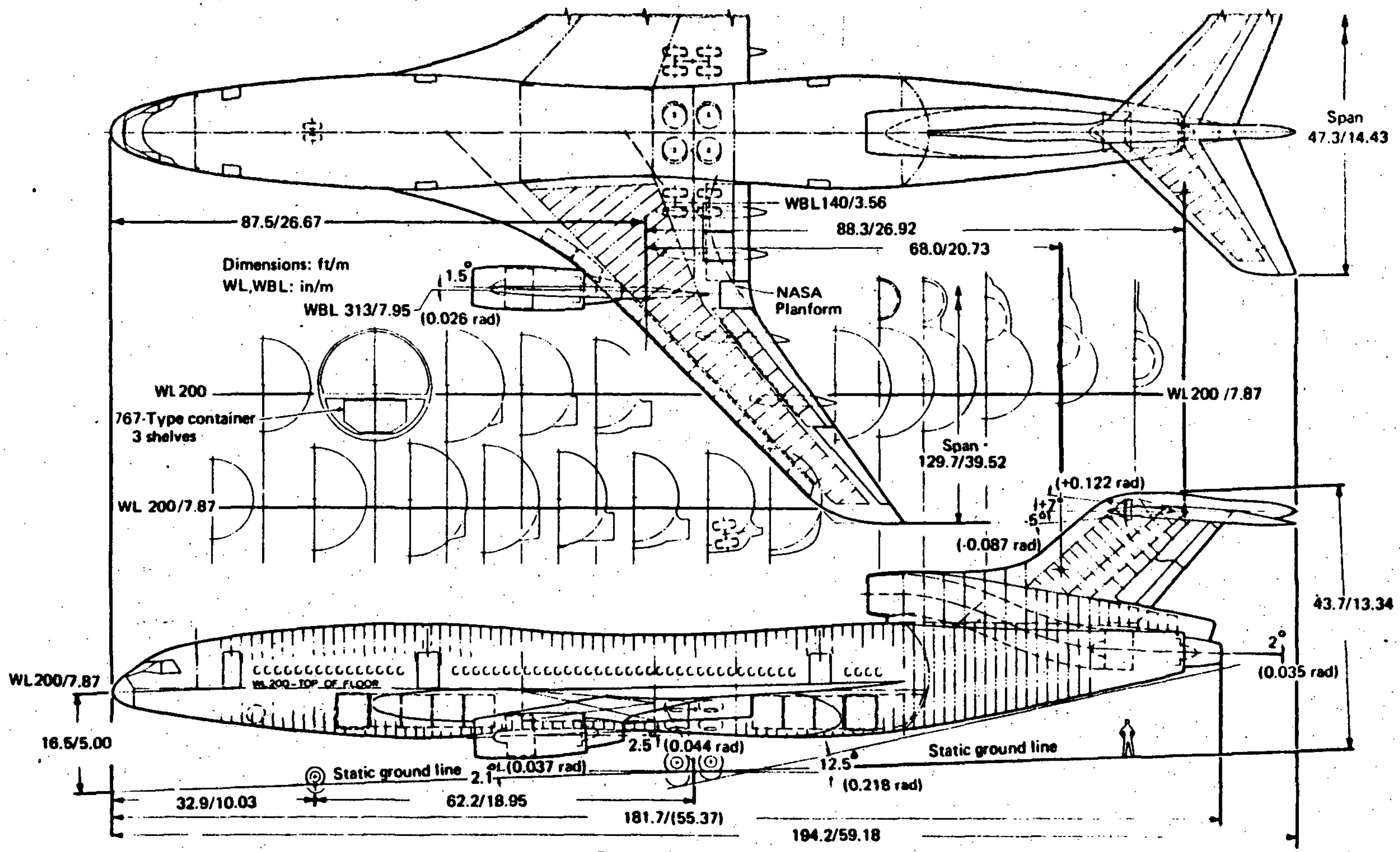
FIGURE 1B



General arrangement

TBC - 630

FIGURE 1C



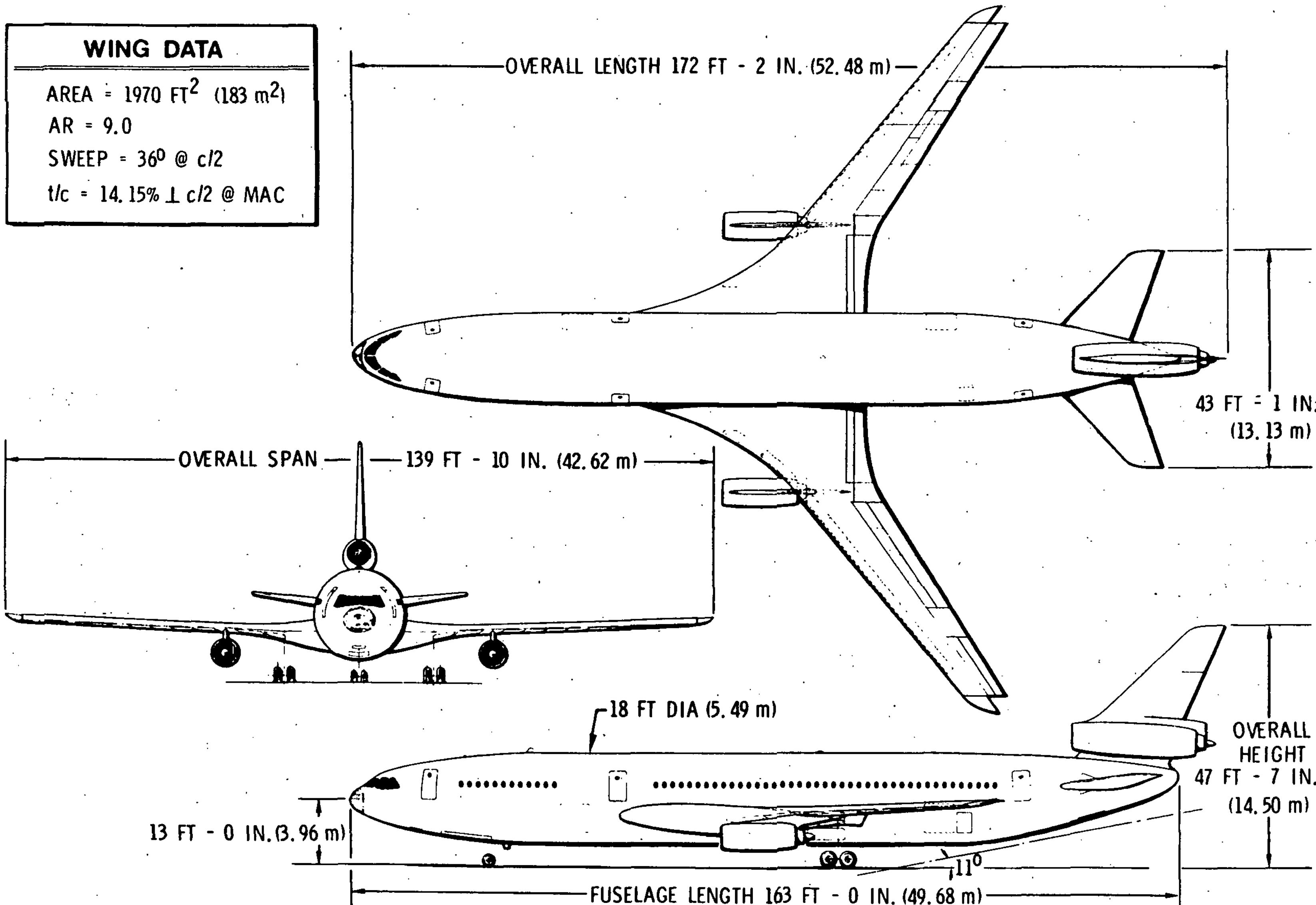
General Arrangement

TBC - 620

FIGURE 1D

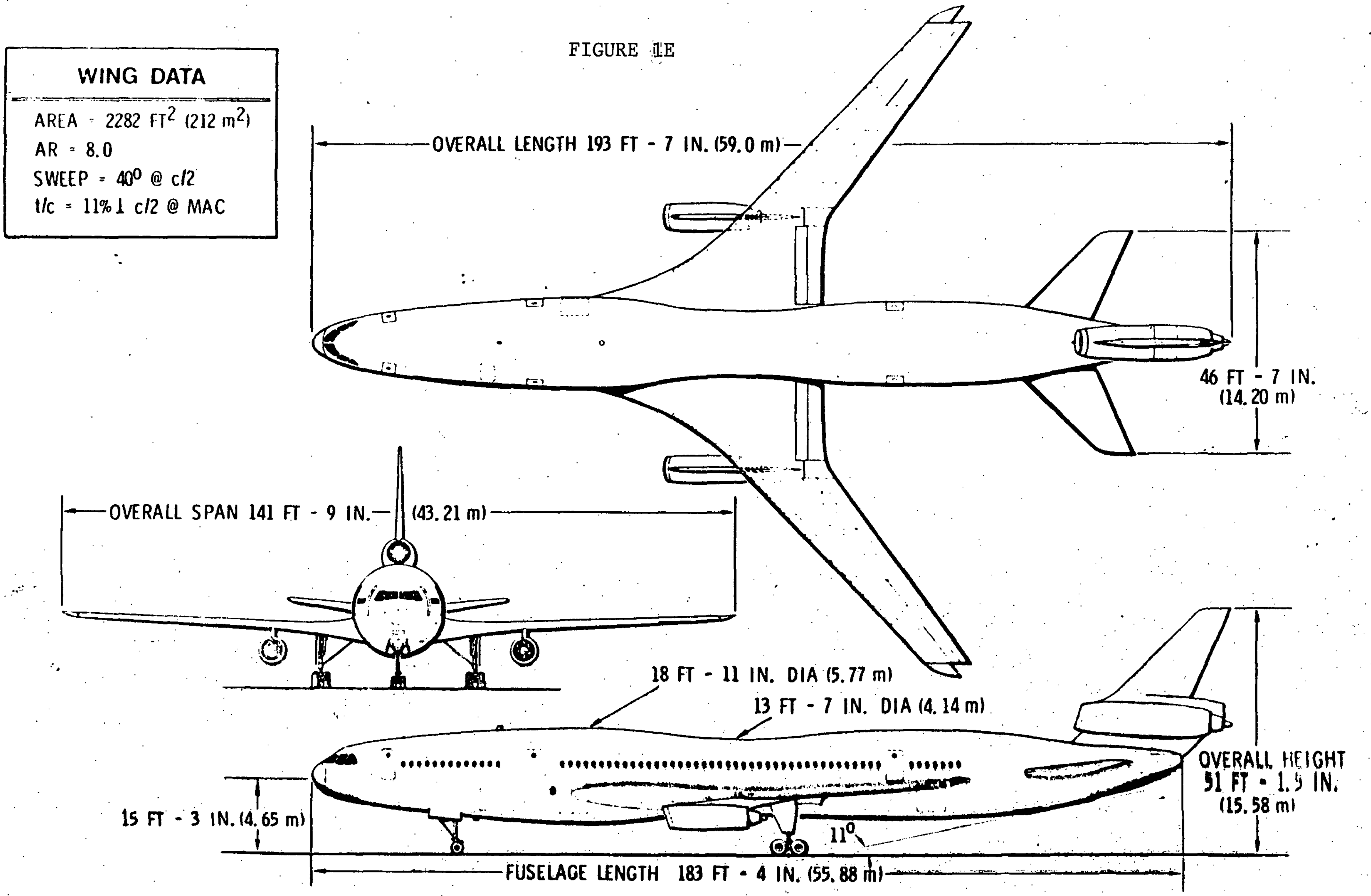
WING DATA

AREA = 1970 FT^2 (183 m^2)
AR = 9.0
SWEEP = 36^0 @ c/2
t/c = 14.15% ⊥ c/2 @ MAC



GD/FW - .90M

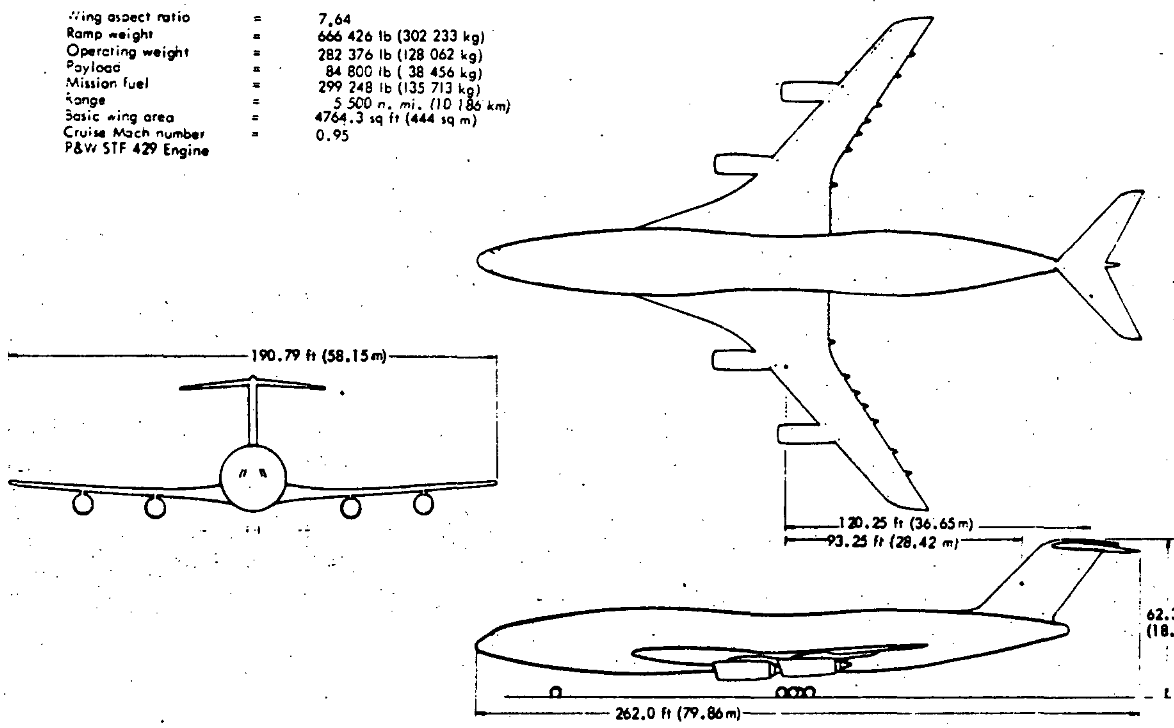
FIGURE 1E



GD/FW - .98M

FIGURE 1F

Wing aspect ratio	=	7.64
Ramp weight	=	666 426 lb (302 233 kg)
Operating weight	=	282 376 lb (128 062 kg)
Payload	=	84 800 lb (38 456 kg)
Mission fuel	=	299 248 lb (135 713 kg)
Range	=	5 500 n. mi. (10 186 km)
Basic wing area	=	4764.3 sq ft (444 sq m)
Cruise Mach number	=	0.95
P&W STF 429 Engine		



GLAC - .95M

FIGURE 2A

PAYLOAD ○ RANGE ENVELOPES

TBC

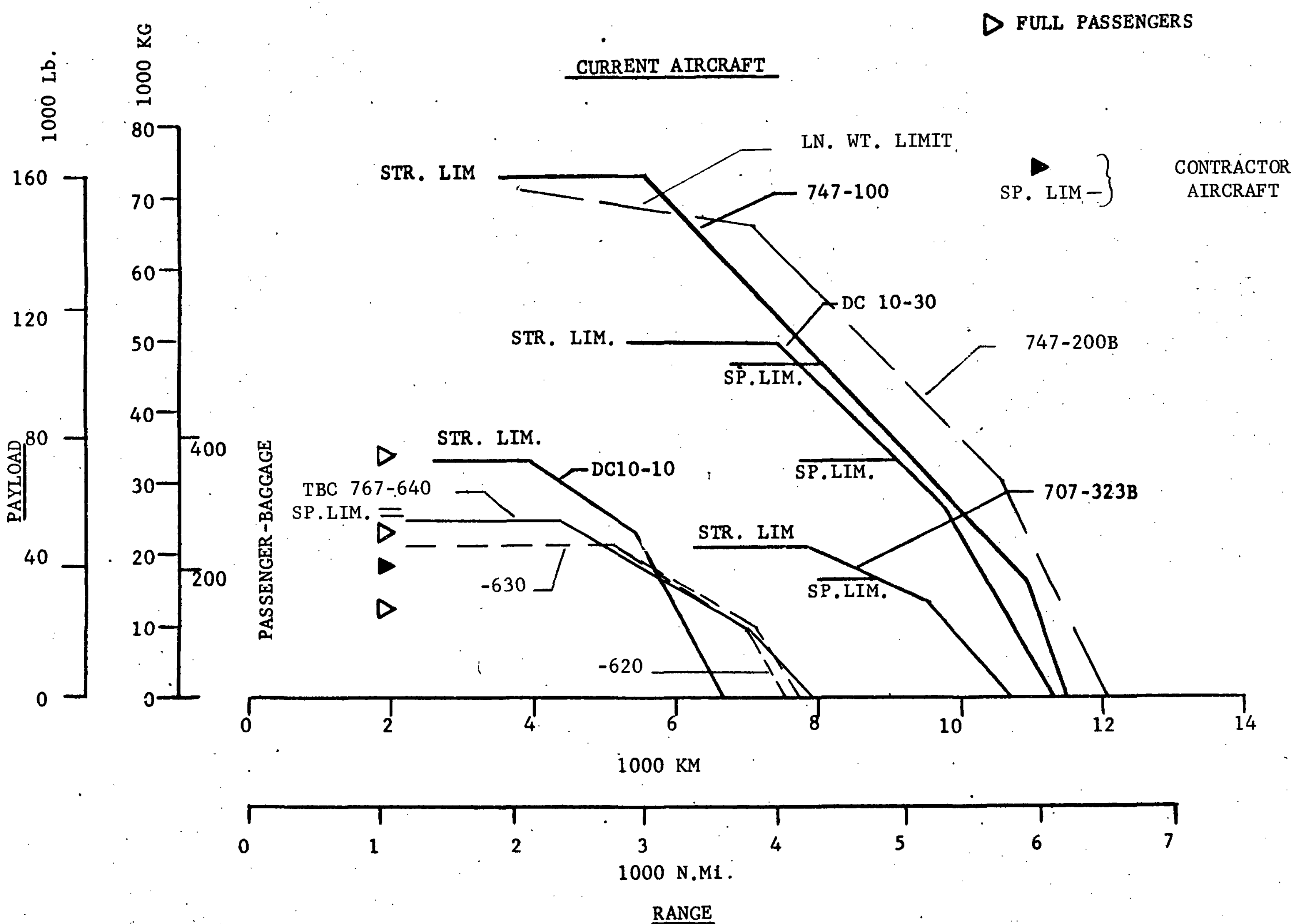
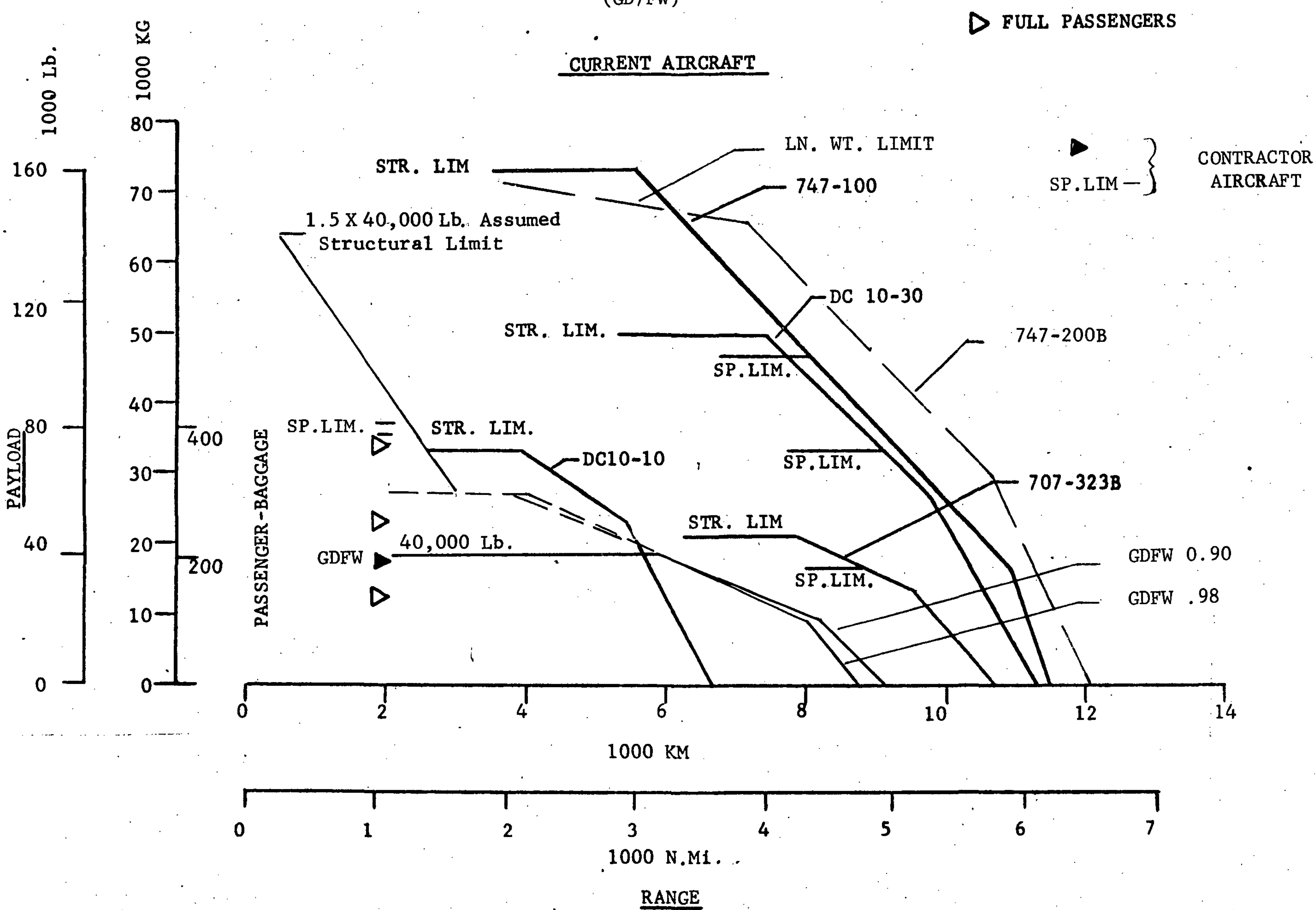


FIGURE 2B

PAYLOAD o RANGE ENVELOPES

(GD/FW)

CURRENT AIRCRAFT



9/73

FIGURE 2C

PAYLOAD ° RANGE ENVELOPES

(GLAC)

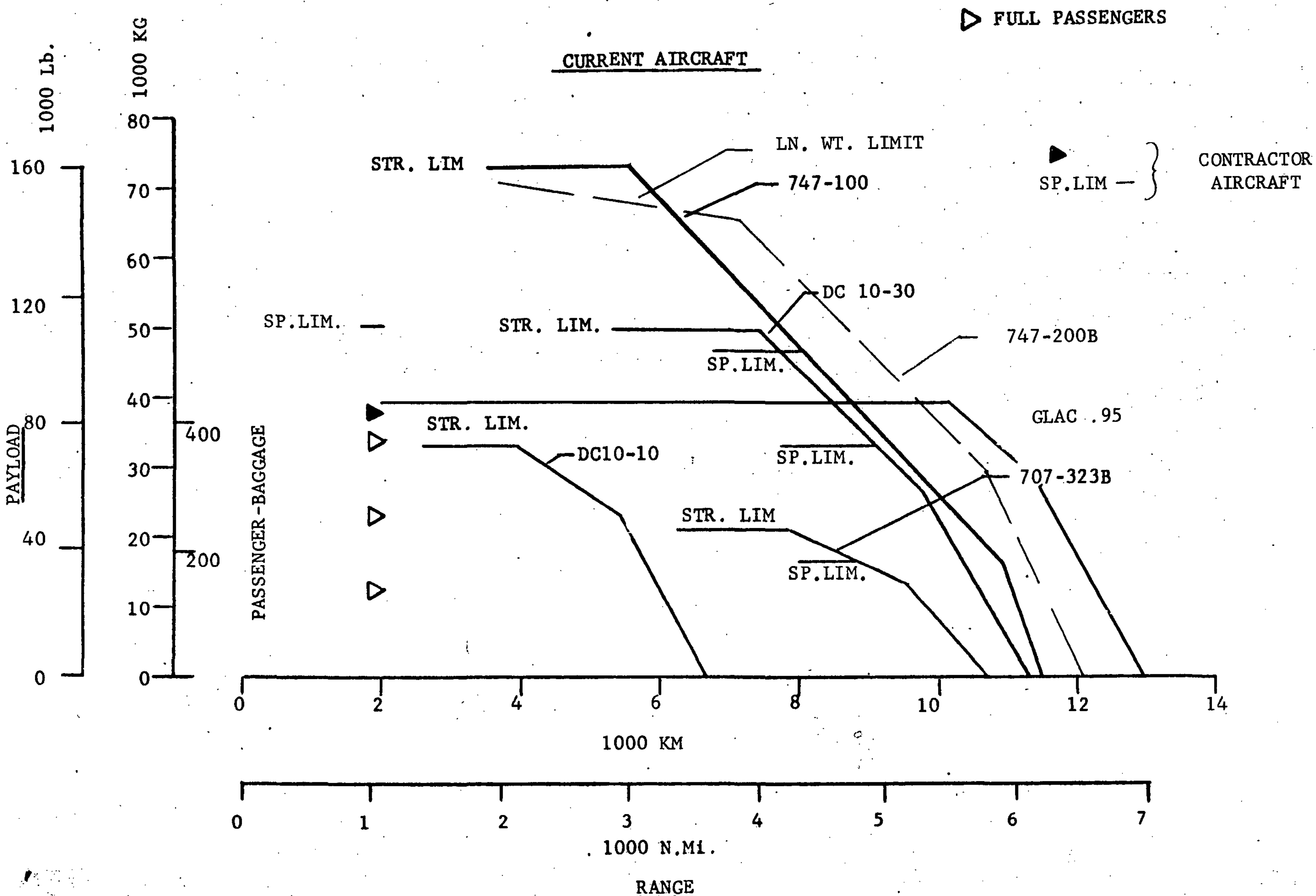
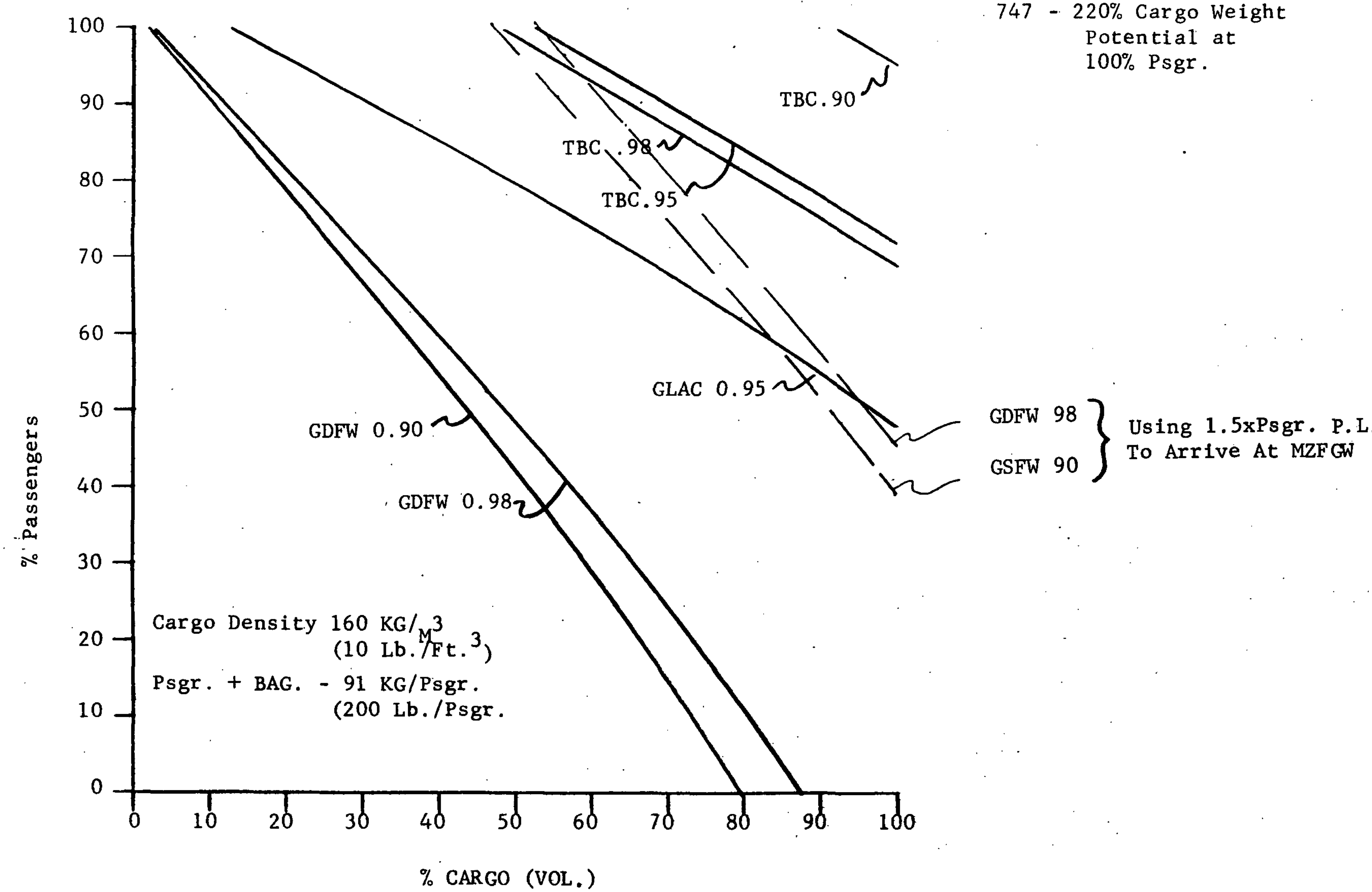


FIGURE 3

PASSENGER/CARGO POTENTIAL

Note:

747 - 220% Cargo Weight Potential at 100% Psgr.



(Limited by Structural Capacity)

8-13-73

FIGURE 4

STRUCTURAL EFFICIENCY

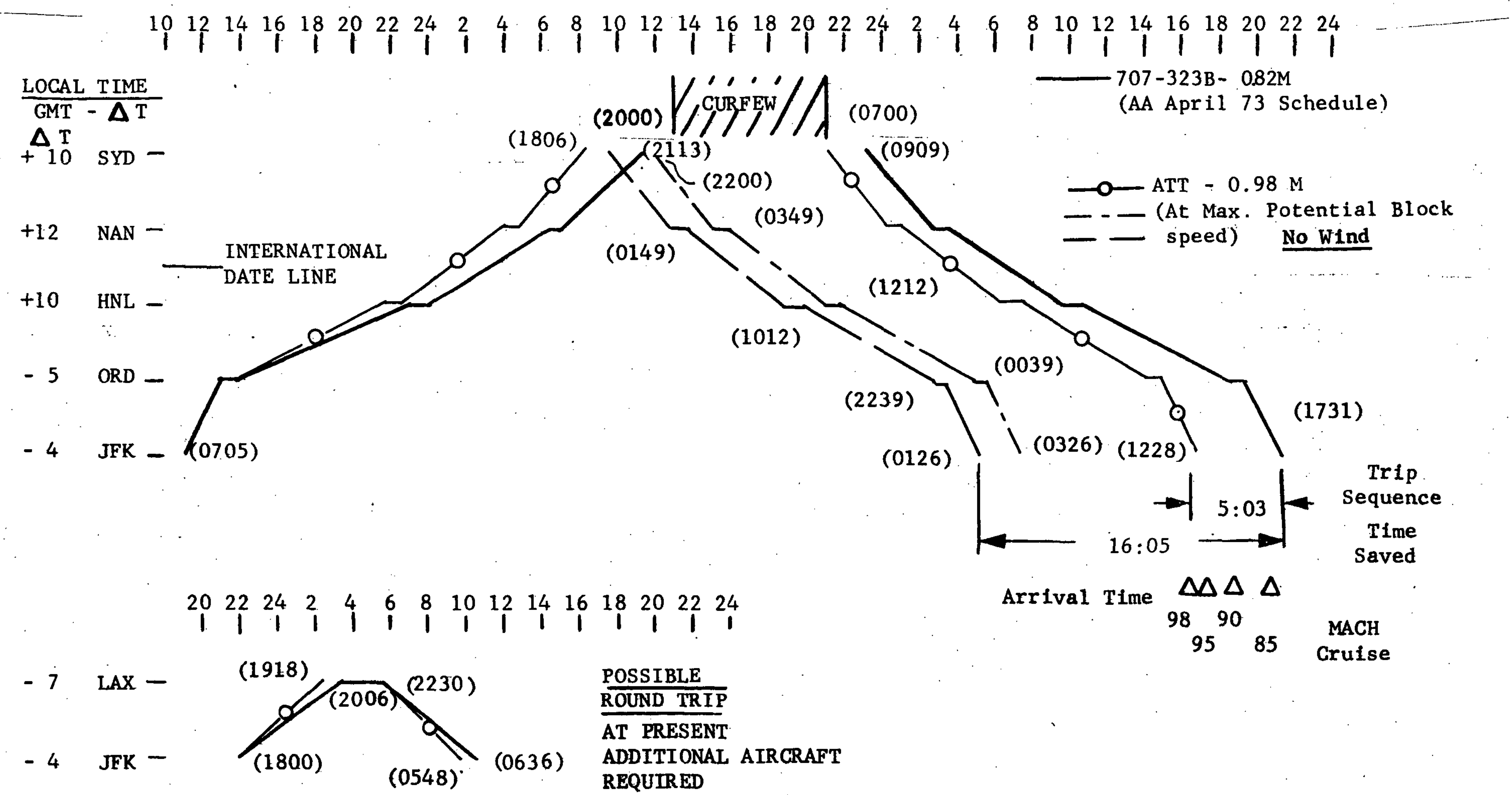
		EOW LB	PL(Str.) LB	MZFGW LB	PL/EOW LB	
TBC	640	159550	55450	215000	.3475	***
	630	171292	49710	221000	.2902	***
	620	184840	49160	234000	.2659	***
GDFW	90	127935	40000	167935	.3126	***
	98	144128	40000	184128	.2775	***
GLAC	95	282376	84802	367178	.3003	***
707-323B		147500	46500	194000	.3153	**
DC10 - 10		237722	72778	310500	.3061	**
DC10 - 30		254900	82300	337200	.3228	**
747 - 100		363212	161288	526500	.4040	**
CV-990		122448	37552	160000	.3067	**
GDFW	90	127935	60000	187935	.4689	*
	98	144128	60000	204128	.4163	*

* Design criteria assumed 1.5 x pax PL. Note Vol. I, P.305 of Contractor Report.

** In service EOW.

*** Initial specification EOW.

FIGURE 5
INTERNATIONAL SCHEDULE
GMT



9/73

FIGURE 6

INTERNATIONAL SCHEDULE

B - 220E ECLIF. ROUTING 9/15/73 NO.11 SCHEDULE

FLIGHT	STA DEPT	STA ARVL	SEG	G/T	CGT SV CV	ELAP	FREQ	LOCAL TIME		CAB DISTANCE	
SEQ NR P7002		ORIG	SAT					DPTR	ARVL	KM	ST. MI
1 0201	ORD 1405	HNL 2255	6.50	1.00	.16	6.50	J	0905	1255	6827	4243
2 0201	HNL 2355	NAN 0620	6.25	.35	.03	16.15	J	1355	1820	5089	3163
3 0201	NAN 0655	SYD 1125	4.30	11.55	11.32	21.20	S	1855	2125	3168	1969
4 0202	SYD 2320	NAN 0305	3.45	.40	.21	37.00	S	920	1505	3168	1969
5 0202	NAN 0345	HNL 1001	6.16	1.09	.38	43.56	M	1545	0001	5089	3163
6 0202	HNL 1110	ORD 1910	6.00	.45	.05	53.05	M	0110	1410	6827	4243
7 0202	ORD 1955	JFK 2159	2.04	.00	.00	55.54	M	1455	1759	1191	740
			35.50								

AVERAGE THRU TIME .49
AVERAGE T/A TIME 11.55

ATT. 0.98 MACH AIRCRAFT

SEQ NR	P7002	ORIG	SAT					LOCAL TIME	
								DPTR	ARVL
1 0201	ORD 1405	HNL 2135	7.30	1.00	.22	7.30	J	0905	1135
2 0201	HNL 2235	NAN 0402	5.27	.35	.08	13.57	J	1255	1602
3 0201	NAN 0437	SYD 0831	3.54	12.29	12.09	18.25	S	1637	1831
4 0202	SYD 2100	NAN 0015	3.15	.40	.24	34.10	S	0700	1215
5 0202	NAN 0055	HNL 0614	5.19	1.09	.42	40.09	M	1255	2014
6 0202	HNL 0723	ORD 1411	6.48	.45	.11	48.06	M	2123	0911
7 0202	ORD 1456	JFK 1644	1.48	.00	.00	50.39	M	0956	1244
			34.01						

AVERAGE THRU TIME .49
AVERAGE T/A TIME 12.29

SYMBOLS

S	SUN	R	THU
M	MON	F	FRI
T	TUE	J	SAT
W	WED	E	EXCEPT

FIGURE 7

AmericanAirlines B747 ROUTING CHART

EFFECTIVE: SEPTEMBER 15, 1973 CHART NO. 73-7

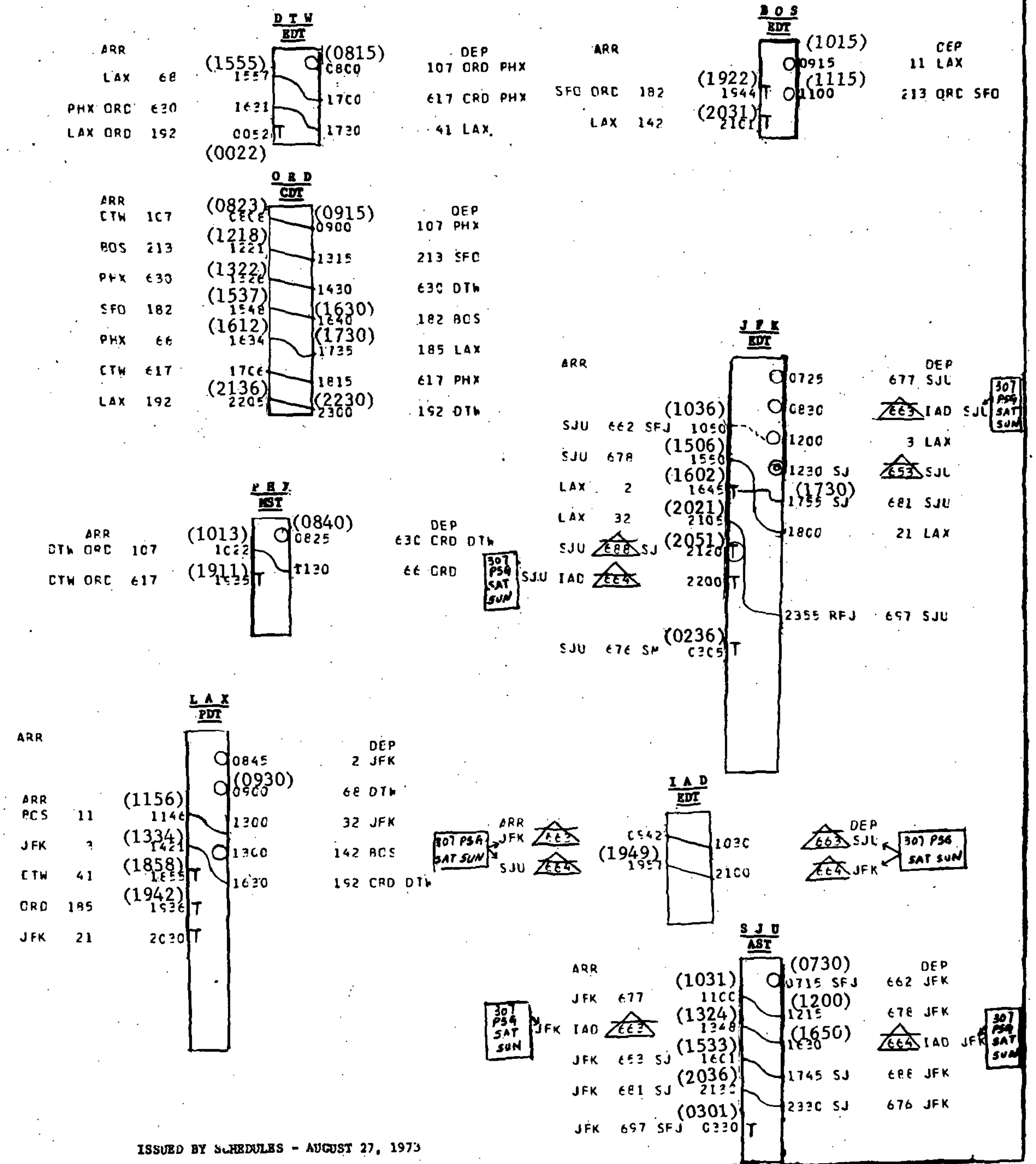
ASSIGNMENT OF AIRCRAFT @ 0600	
City	B-747 Sched
BOS	2
DTW	1
JFK	3
LAX	3
PHX	1
SFO	1
SJU	1
	12
CHRTR	1 (JFK)
UNASSGD	2 (LAX)
	1 (TULE)
FLEET	16

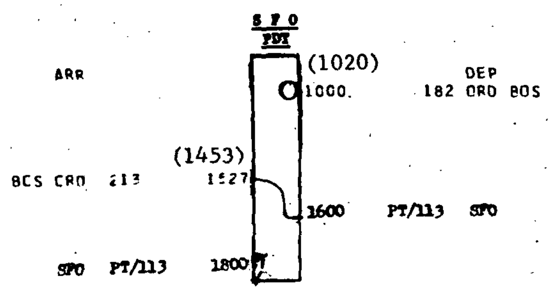
RAMP/RAMP HOURS SCHEDULED DAILY	
HOURS	**100:05*
TOTAL FLEET	16
UTILIZATION	**6:15*
ACTIVE FLEET	12
UTILIZATION	**8:20*

*Frequency Operation Included (Hours do not include Pilot Training)

**Includes Caribbean Operation

B-747/384





(TIME) - M .98 ATT AIRCRAFT *

* NOTE: Scheduled Times Reflect An Actual Operation With ATC, En Route, Ground Track, Wind ... etc. Considerations.

ISSUED BY SCHEDULES - AUGUST 27, 1973

ADVANCED TECHNOLOGY AIRCRAFT SCHEDULE

FIGURE 8

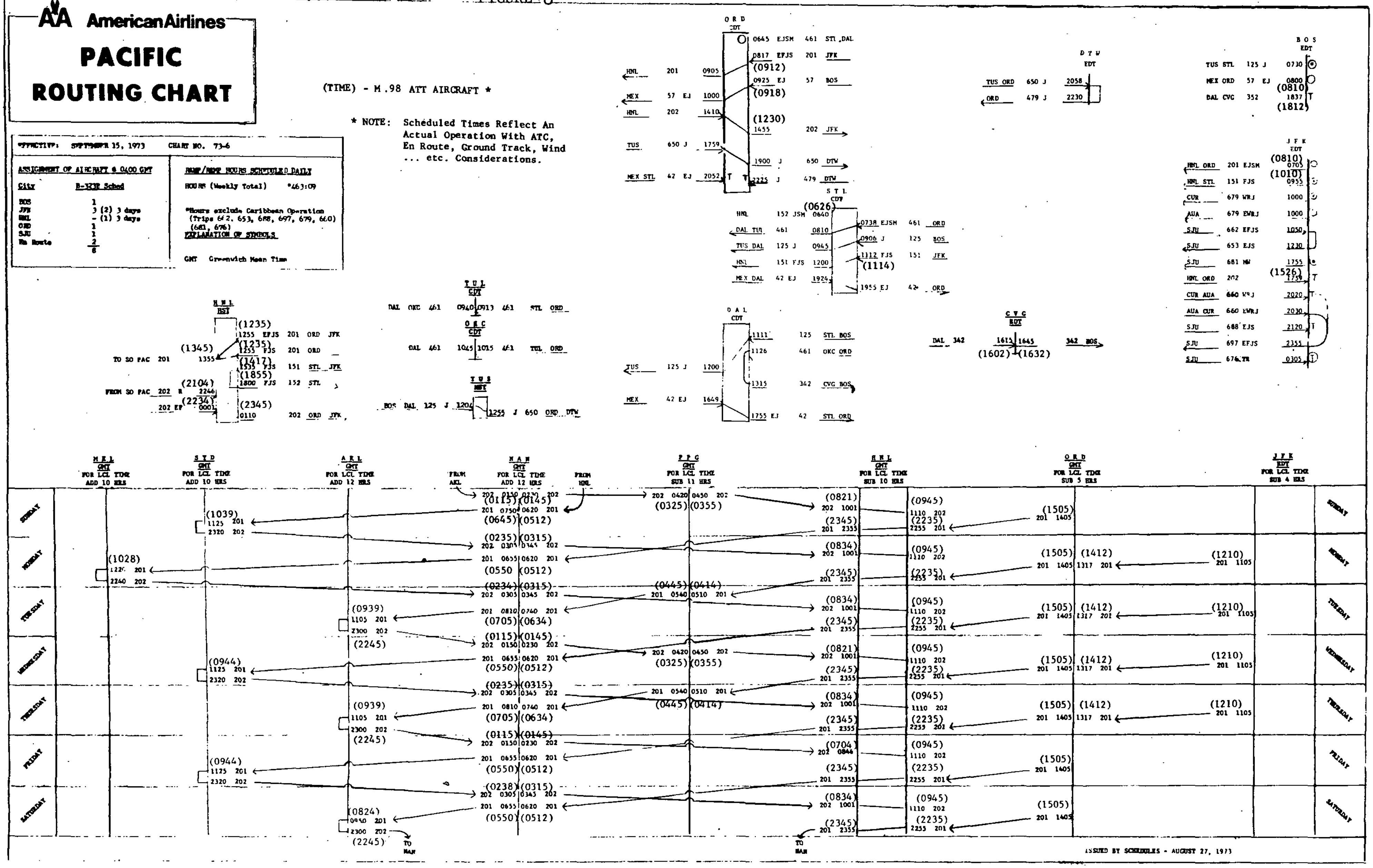


FIGURE 19
FUEL UTILIZATION TRENDS
747-100

INTERNATIONAL

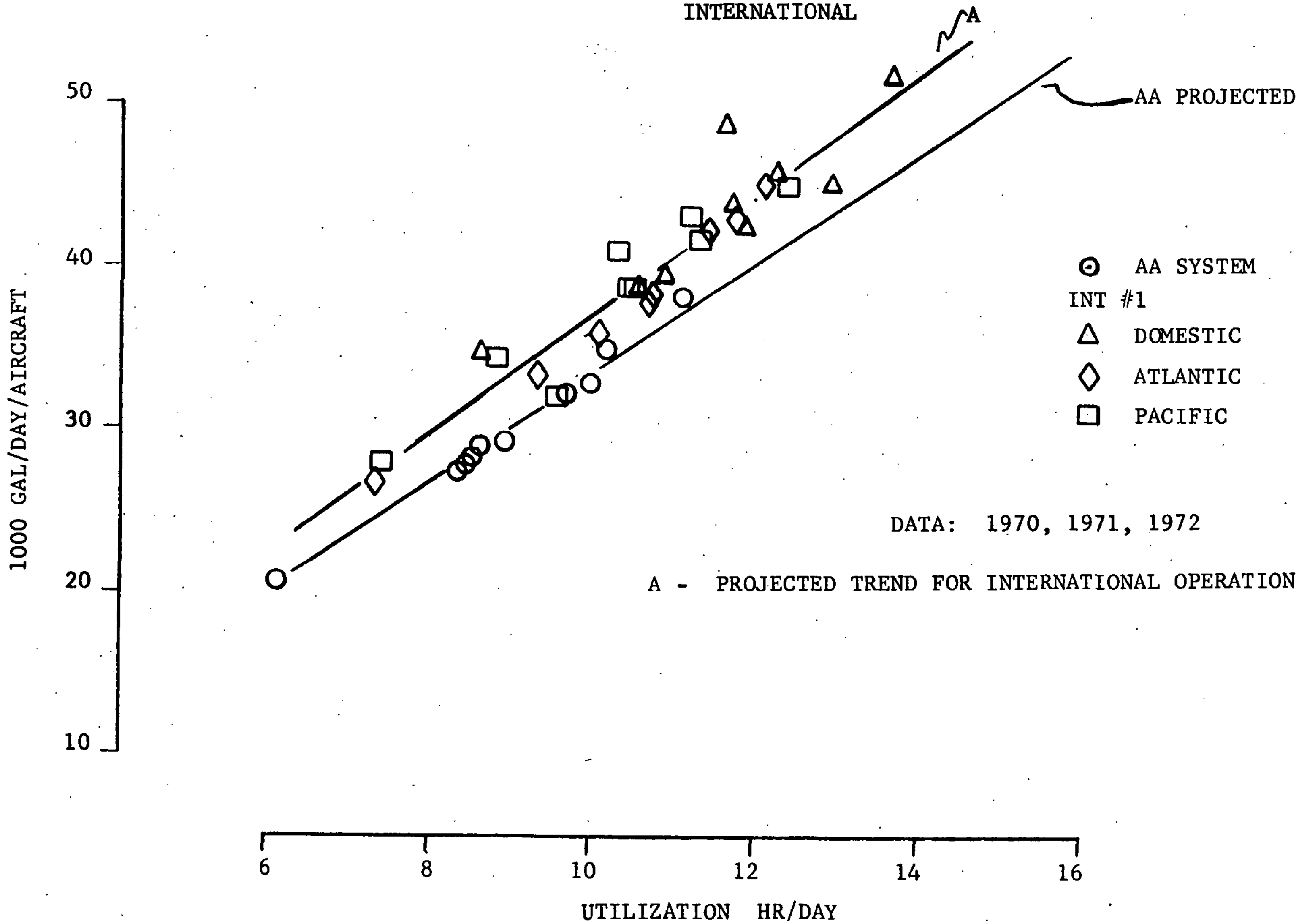


FIGURE 10

FUEL UTILIZATION – ATT

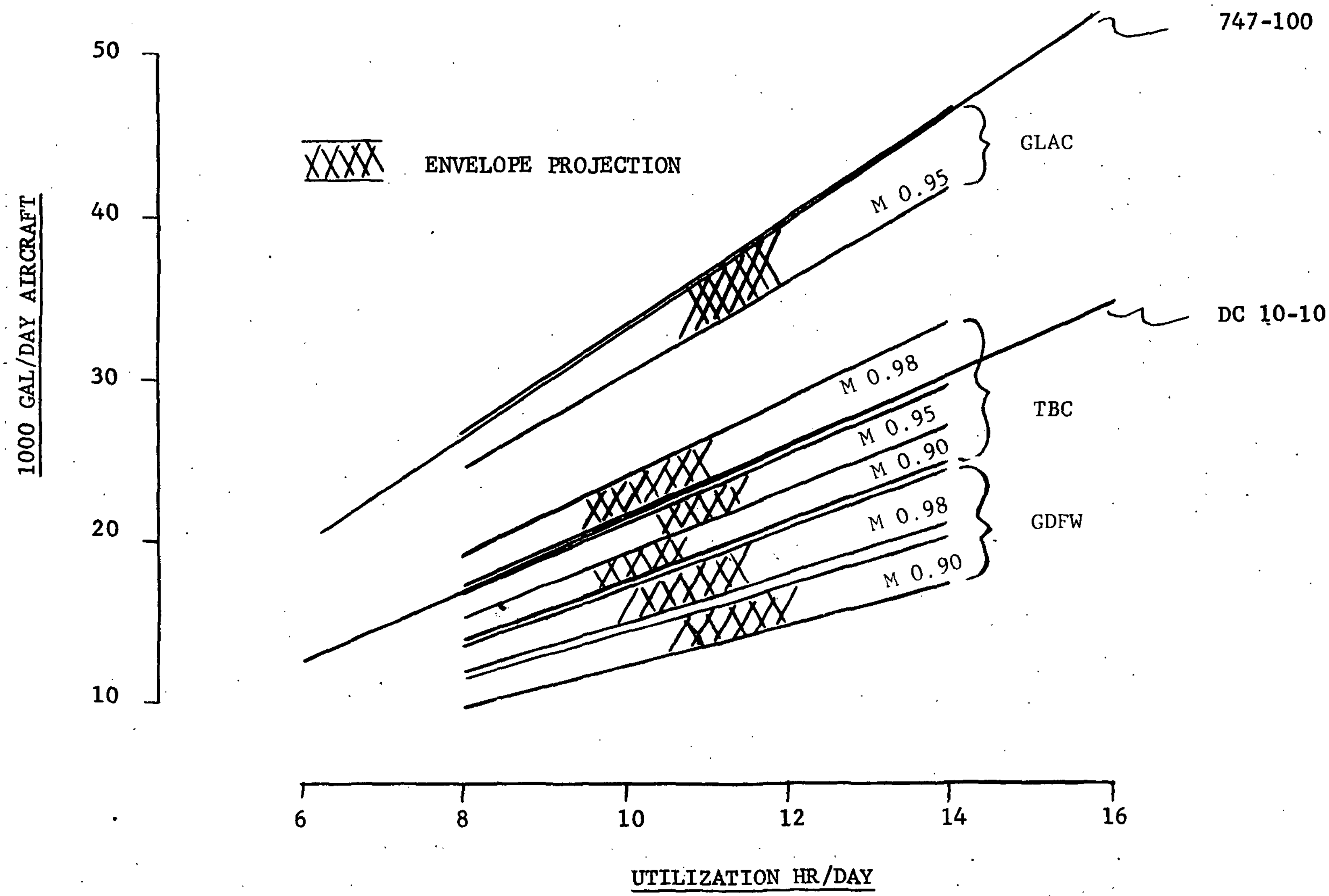


FIGURE 11

FUEL INDEX
JFK-LAX
3982 KM

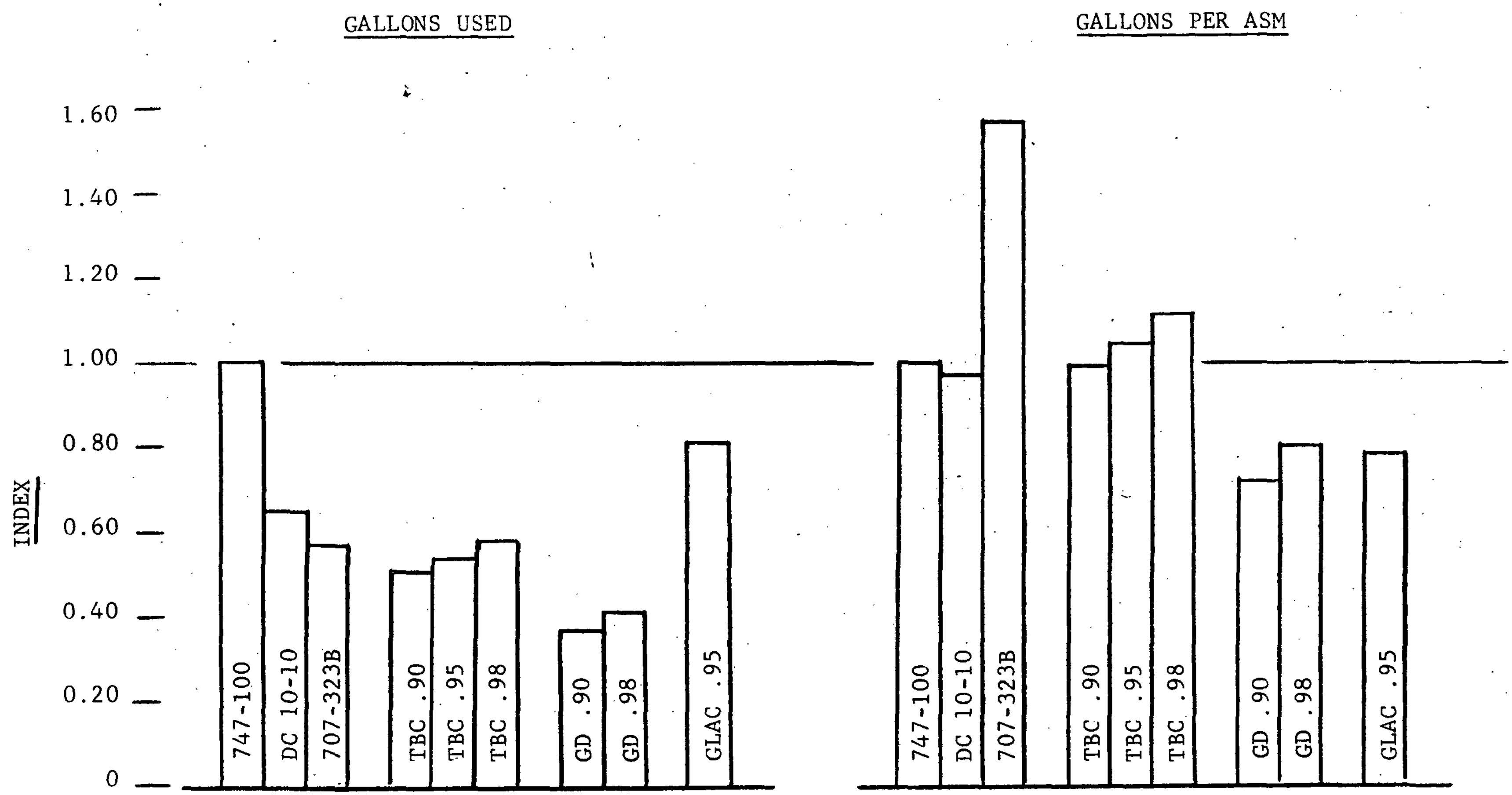


FIGURE 12
PREMATURE COMPONENT REMOVALS SUMMARY
(1972)

	Hourly Cost Index[4]			Annual Removal Index		
	707	747	DC-10[2]	707	747	DC-10[2]
		By Aircraft			By Component	
Auto-Flight						
Selected Subdivisions						
o Basic Autopilot	1.0	1.76	6.78	1.0	0.26	0.63
o Yaw Damper	1.0	1.34	6.65	1.0	0.39	1.54
o Auto-control[1]	1.0	.04	2.62	1.0	0.01	0.36
Total Auto-flight System	1.0	1.76	5.69	1.0	0.23	0.60
Navigation						
Selected Subdivisions						
o Altitude Instruments	1.0	1.00	.44	1.0	0.077	0.044
o HDI/ADI	1.0	3.45	3.27	1.0	0.312	0.226
o MAg.Comp./RMDI/CDI/HSI	1.0	1.59	3.47	1.0	0.268	0.241
o Weather Radar	1.0	.99	.79	1.0	0.139	0.092
o INS	1.0	5.34	NA[3]	1.0	4.48[5]	NA[3]
Total Navigation System	1.0	2.23	1.56	1.0	0.19	0.174

Fleet Size

707 - 46
DC-10 - 25 (7 to 25 during 1972 full fleet in Nov.) 54% size of 707 fleet.
747 - 16 35% size of 707 fleet.

	Total Hourly Maintenance Cost Index		
	707-323B	747	DC-10
Total Maintenance 1972	1.0	2.6	1.7
Total Direct Mntnc. 1972	1.0	3.7	1.9

(1) 707 auto/mach trim
747/DC-10 auto throttle/speed control
index used to show similarity only.
(2) Early fleet data (7 to 25 a/c fleet build up thru '72)
(3) DC-10 fleet has no INS (19 of 707 fleet equipped)
(4) Includes contract, direct labor, & material, based on QLI
(5) 3 month data base in 1972 for 707 a/c (19 equipped two each). Using early 1973 data removal rate is about 2 times as high as 747 - since same major component. (Not valid comparison; shown for reference only.)

FIGURE 13
MATERIAL COST INCREASE

MATERIAL COST ASSUMPTION

COMPOSITE STRUCTURE — 60$/LB
ALUMINUM STRUCTURE — 1$/LB

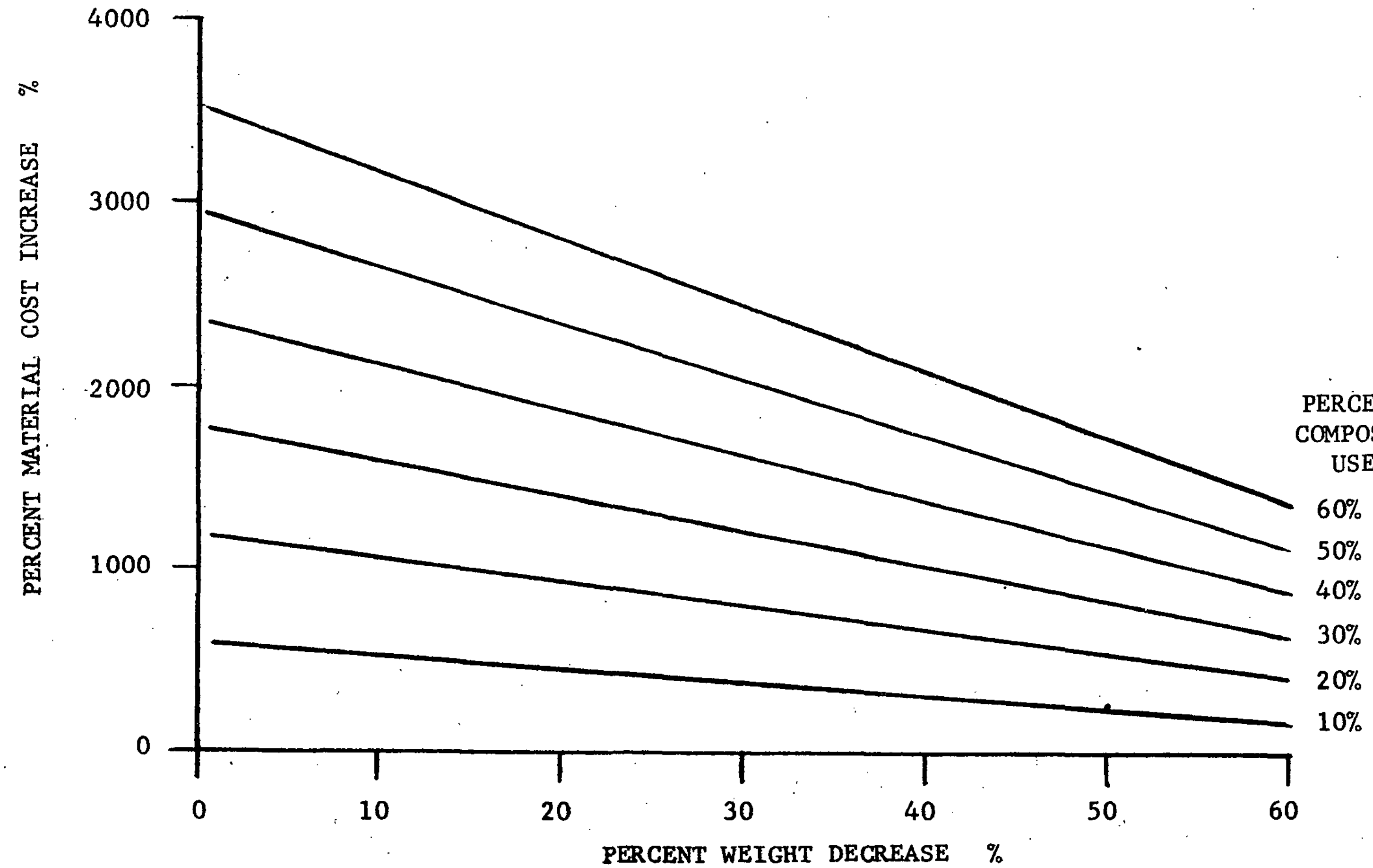


FIGURE 14

MATERIAL COST INCREASE

Material Cost Assumption
Composite Structure 30$/lb.
Other Structure 1$/lb.

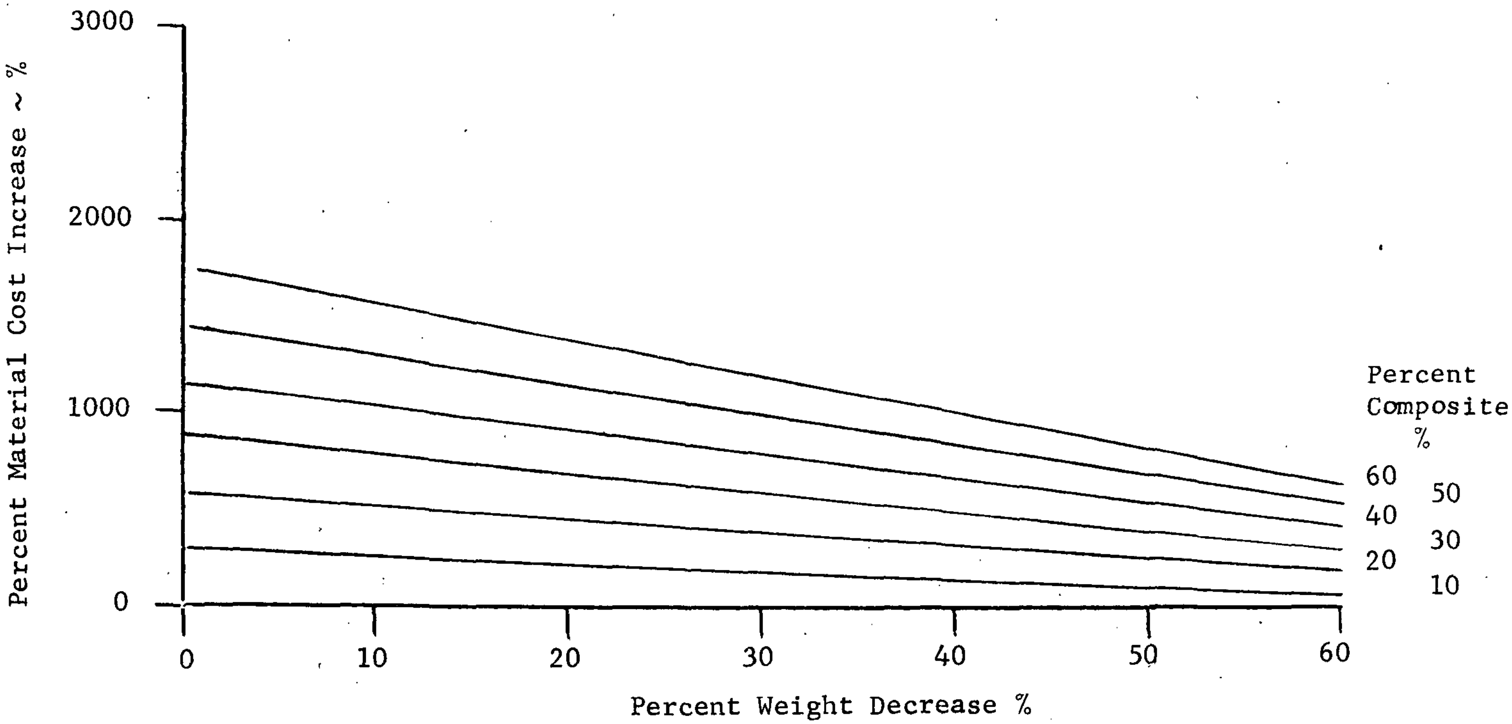
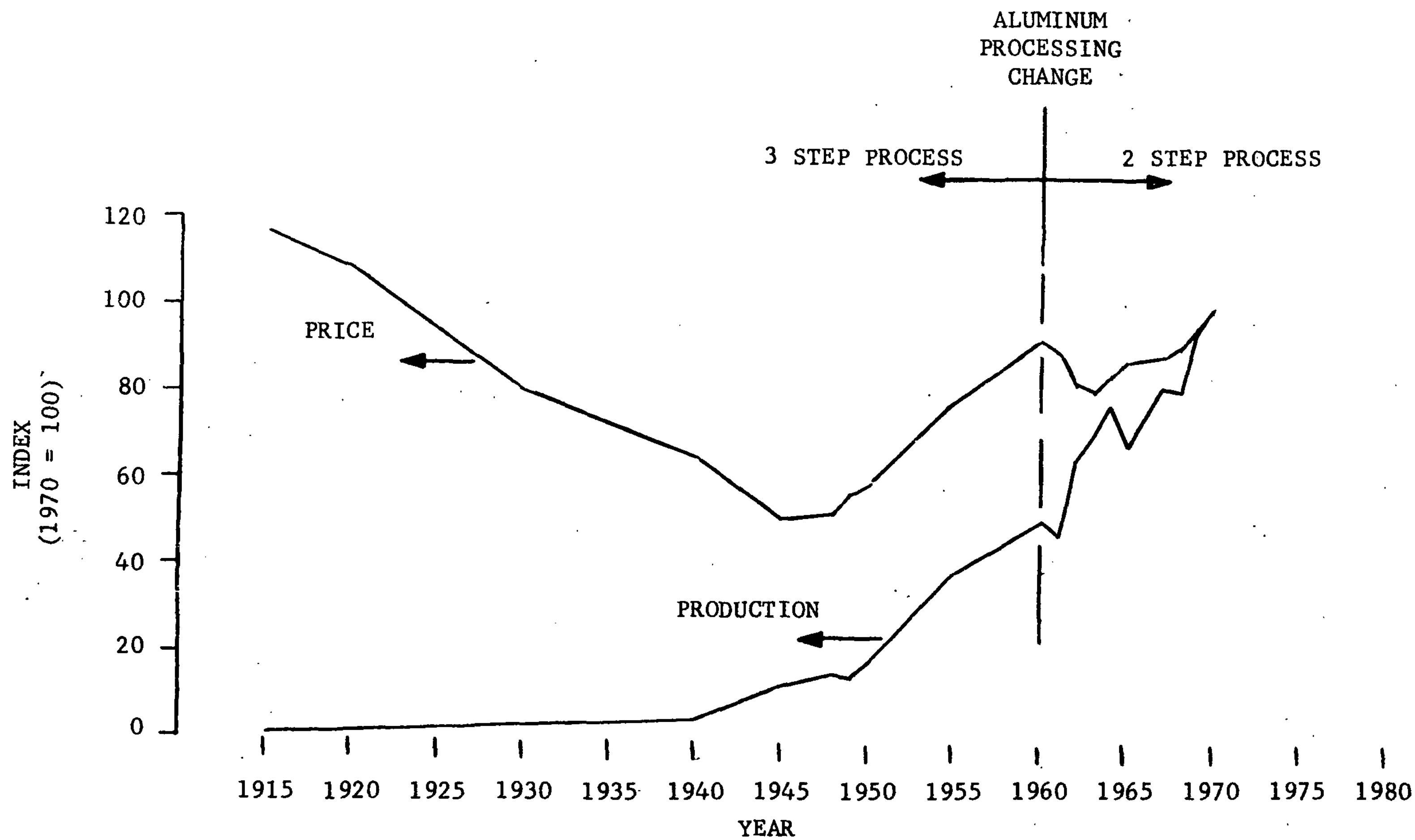


FIGURE 15
PRIMARY ALUMINUM INGOT



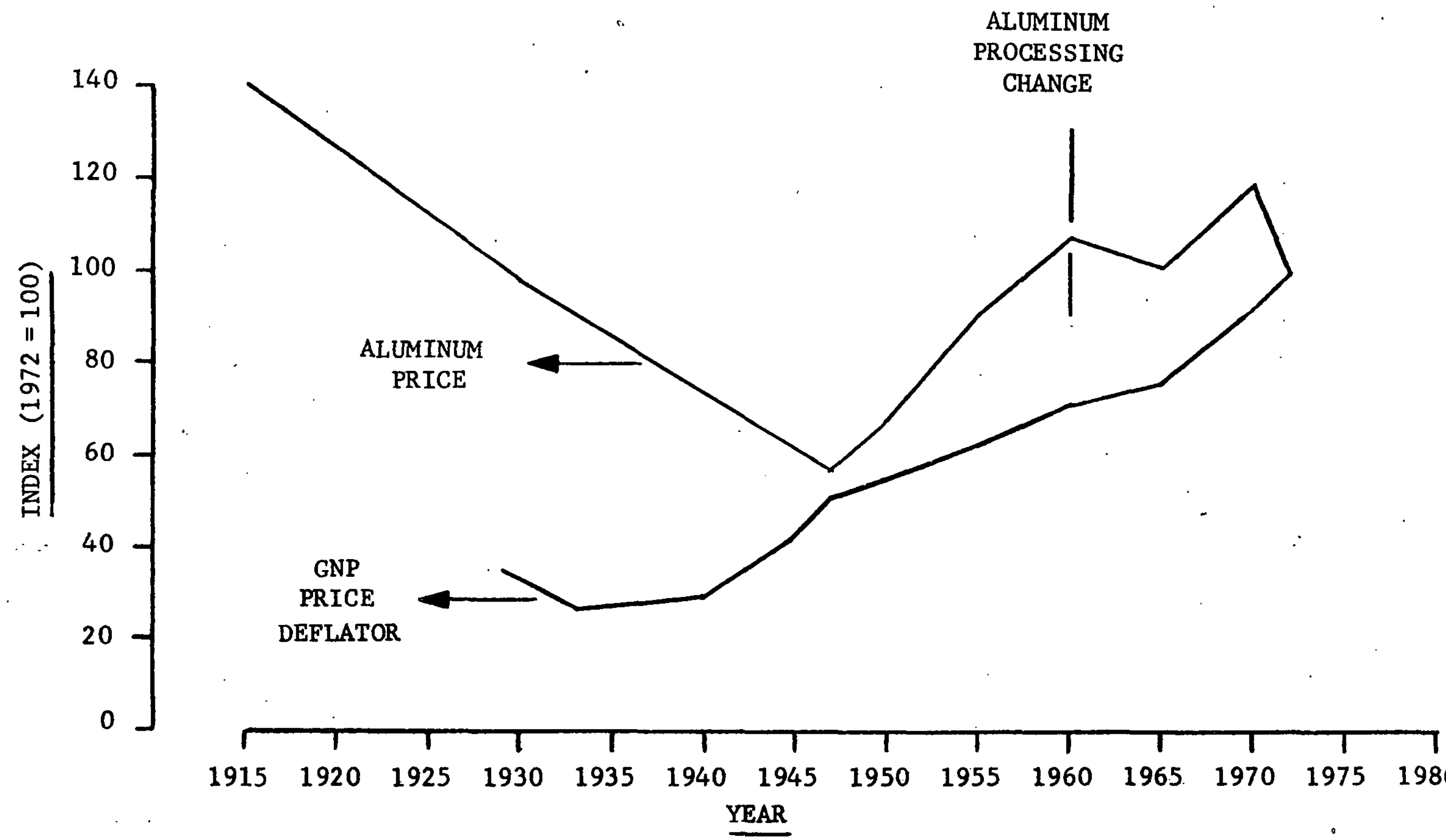
SOURCE: STATISTICAL ABSTRACT OF THE U.S. 1971

9/3/73

FIGURE 16

PRICE TRENDS

PRIMARY ALUMINUM INGOT



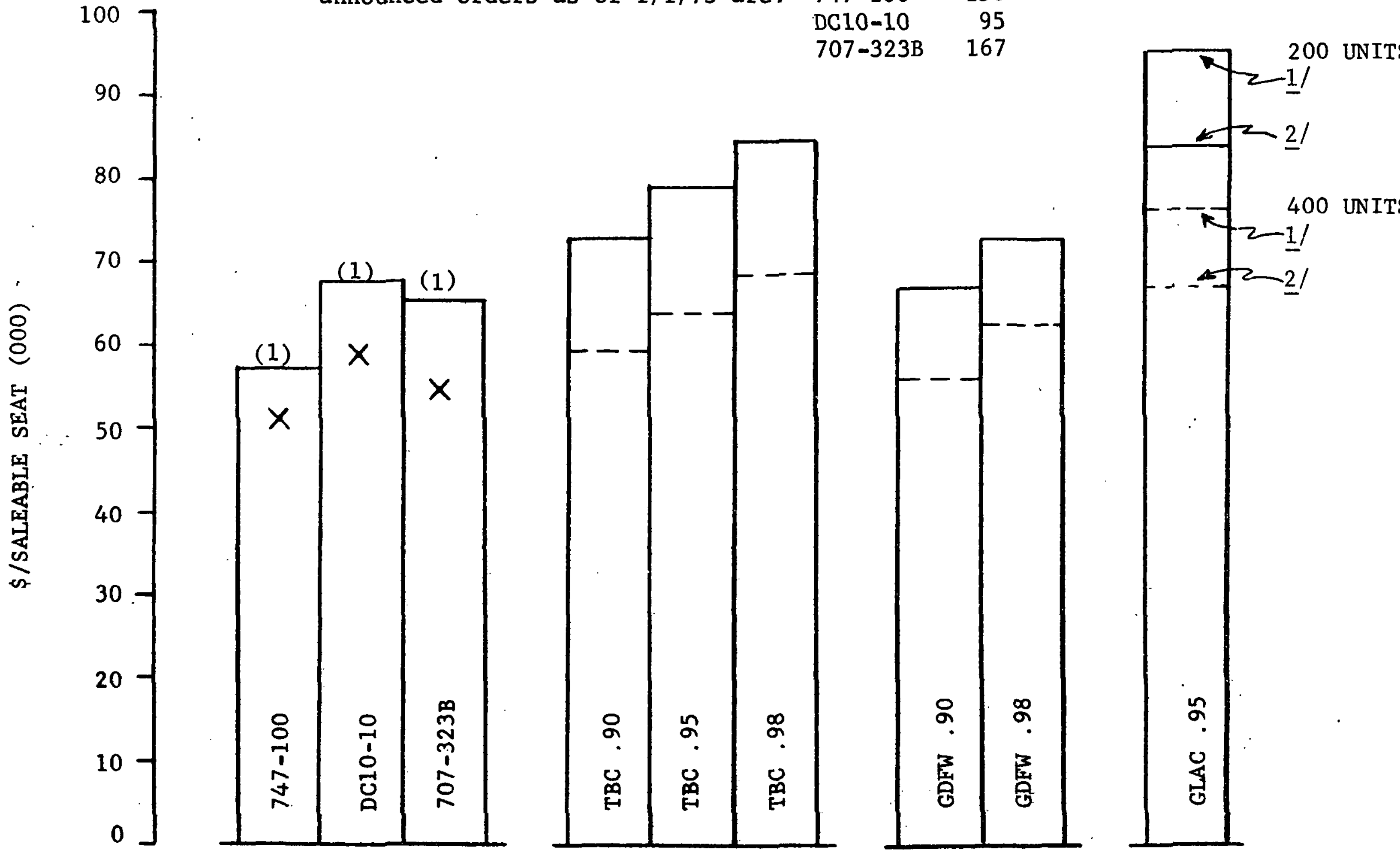
DATA SOURCE: 1) 1971 BUSINESS STATISTICS - U.S. DEPT. OF COMMERCE
2) STATISTICAL ABSTRACT OF U.S. 1950 THRU 1972
3) BUREAU OF LABOR STATISTICS - NYC

FIGURE 17
INVESTMENT PER SEAT
1970 $

1/ GLAC Profit Included
2/ GLAC Profit Excluded

(1) Note: Manufacturers do not quote variable prices as a function of sales however, sales and announced orders as of 1/1/73 are:

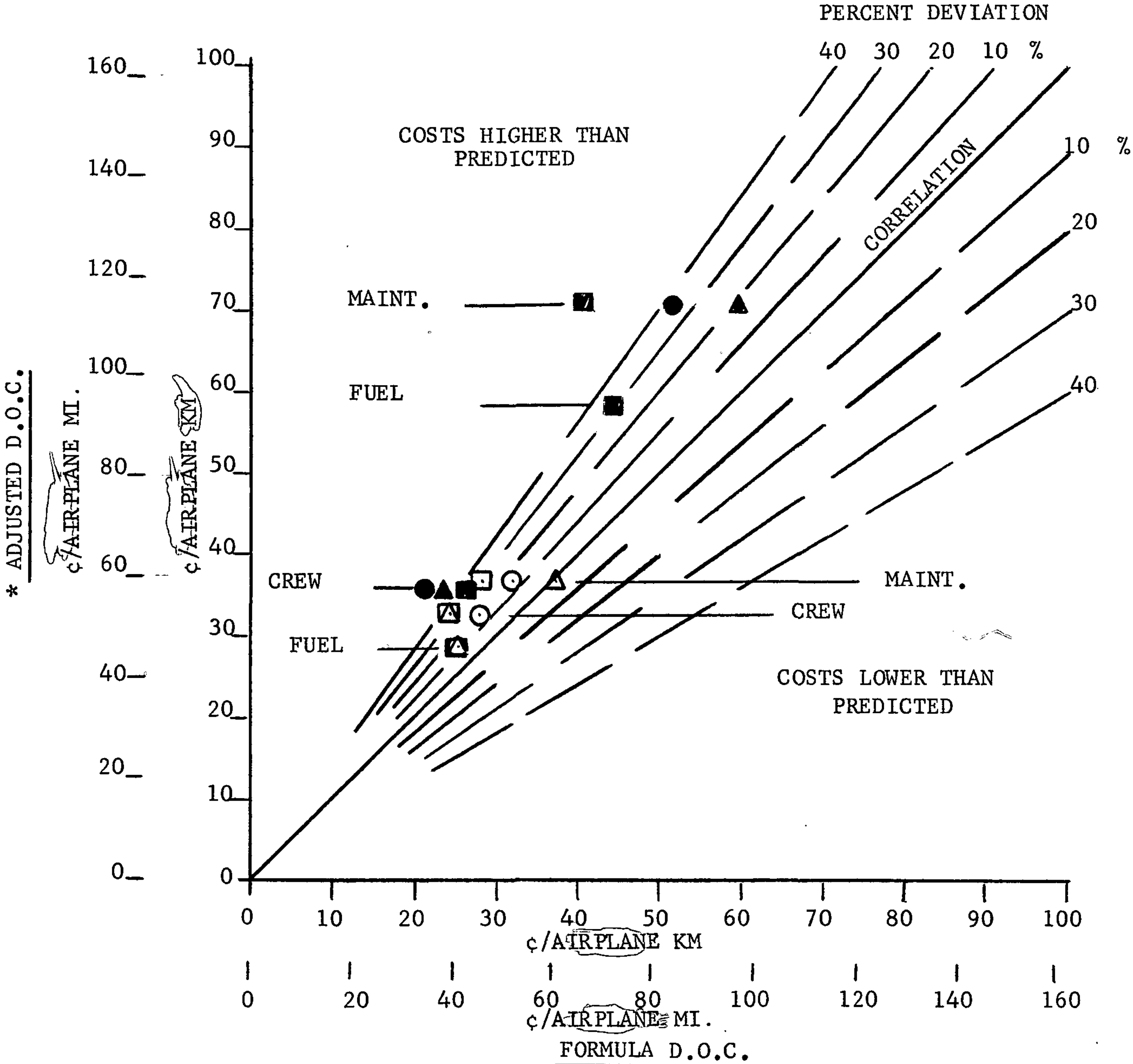
747-100	156
DC10-10	95
707-323B	167



Note: "X" Estimated invoice price exclusive of customer options — comparable to ATT investment.

FIGURE 18

COMPARISON OF ACTUAL AND FORMULA D.O.C.'S



707-323B		747-100
⊙	1967 ATA	●
△	1970 NASA	▲
□	1971 TBC	■

* ACTUAL COSTS WERE ADJUSTED TO ACCOUNT FOR THE UNDERLYING ASSUMPTIONS MADE BY THE CONTRACTORS IN THE FORMULA APPROACH

FIGURE 19A

PAYLOAD REQUIREMENT
MARGIN BETWEEN D.O.C. & POTENTIAL REVENUE
PASSENGER & CARGO OPERATION
1972 $

GDFW

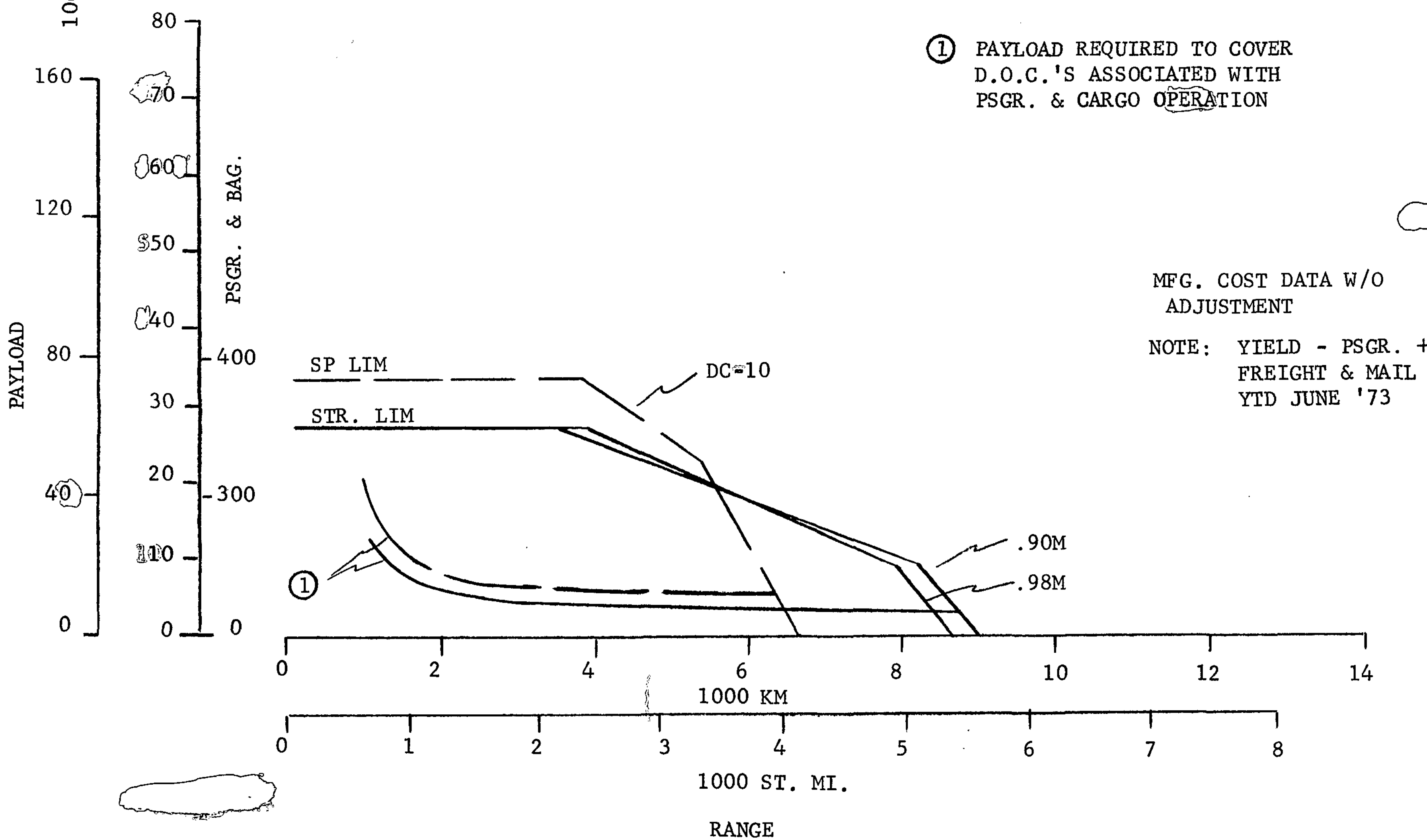


FIGURE 19B

PAYLOAD REQUIREMENT
MARGIN BETWEEN D.O.C. & POTENTIAL REVENUE
PASSENGER & CARGO OPERATION
1972 $

TBC

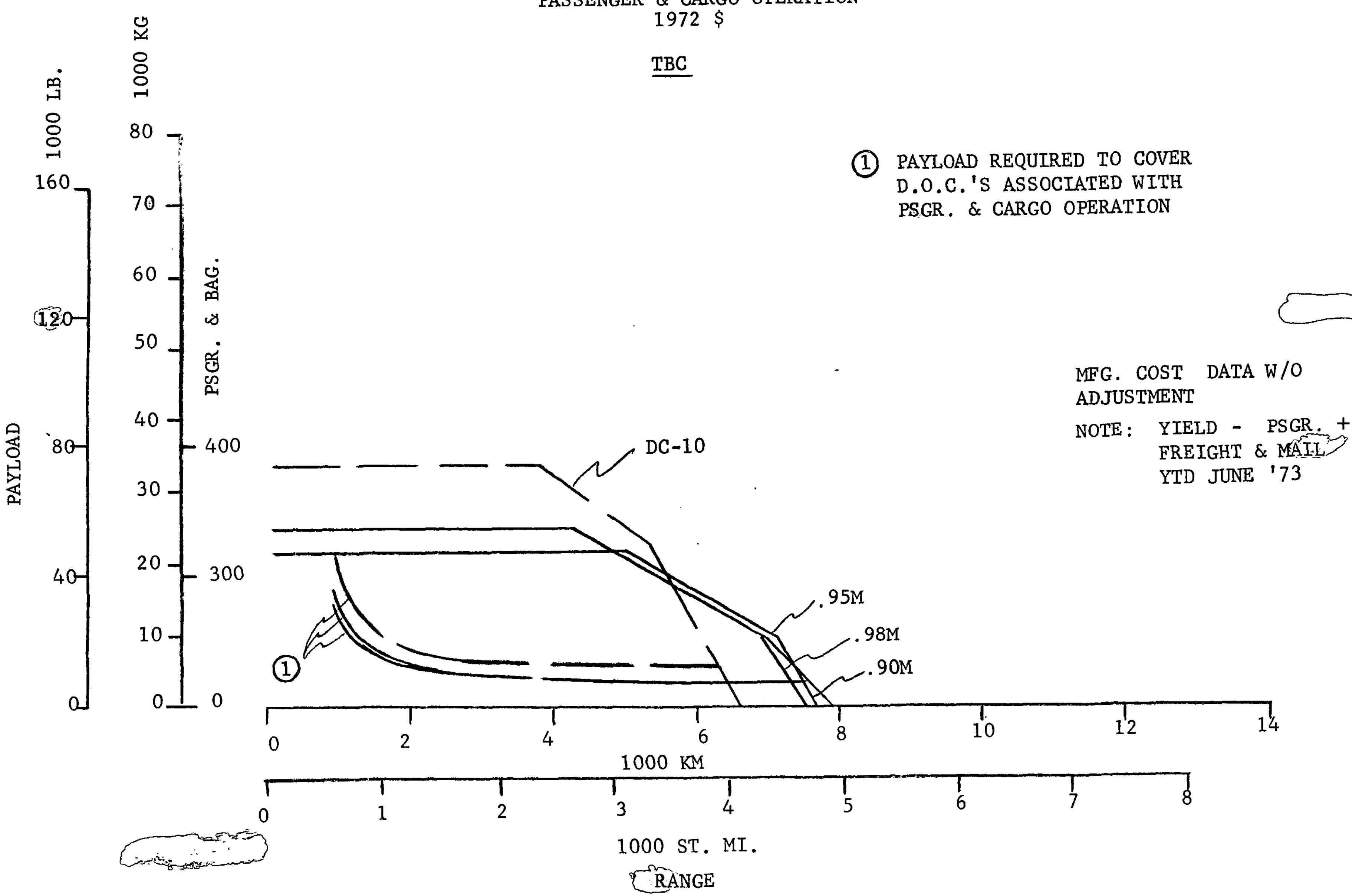


FIGURE 19C

PAYLOAD REQUIREMENT
MARGIN BETWEEN D.O.C. & POTENTIAL REVENUE
PASSENGER & CARGO OPERATION
1972 $

GLAC

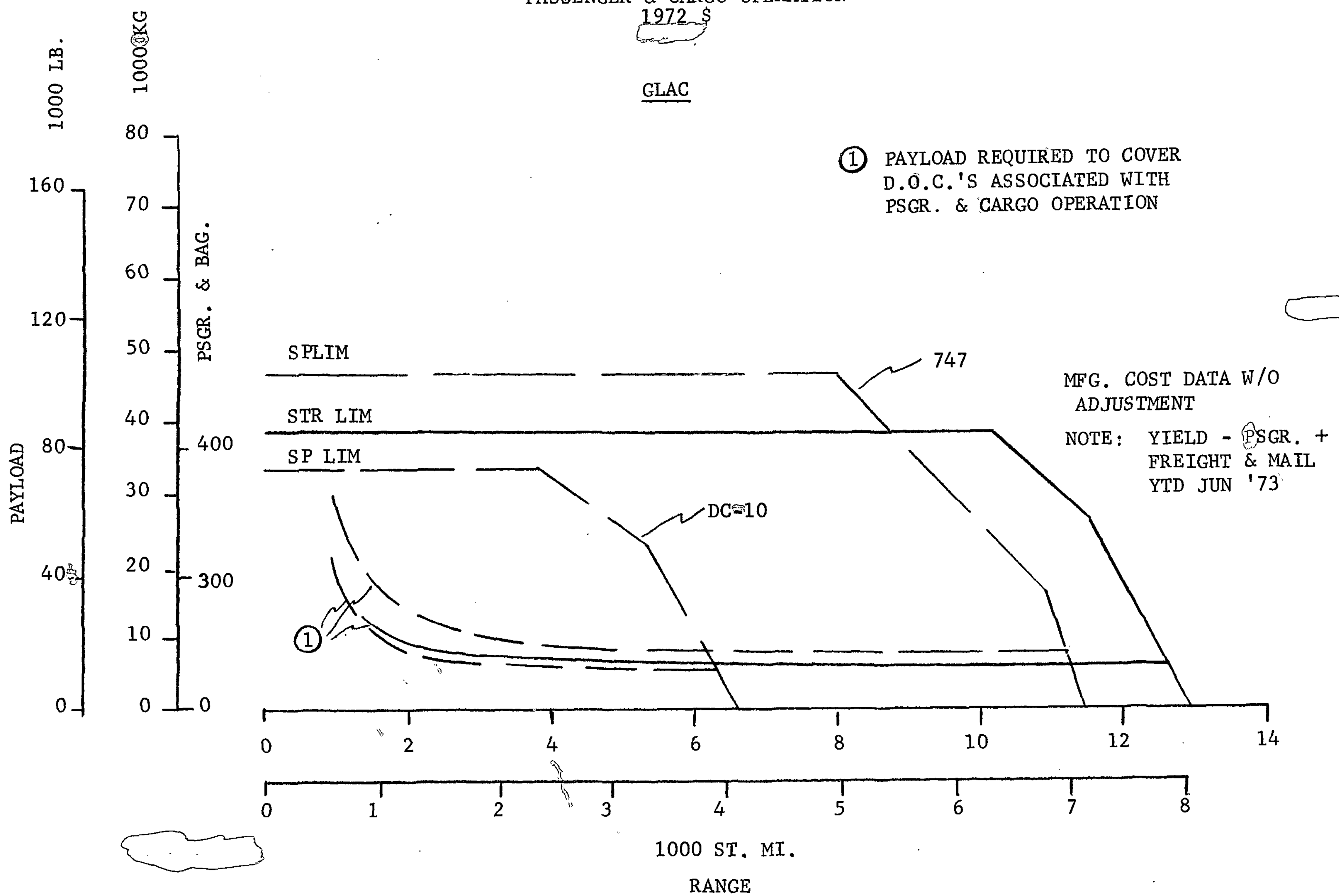
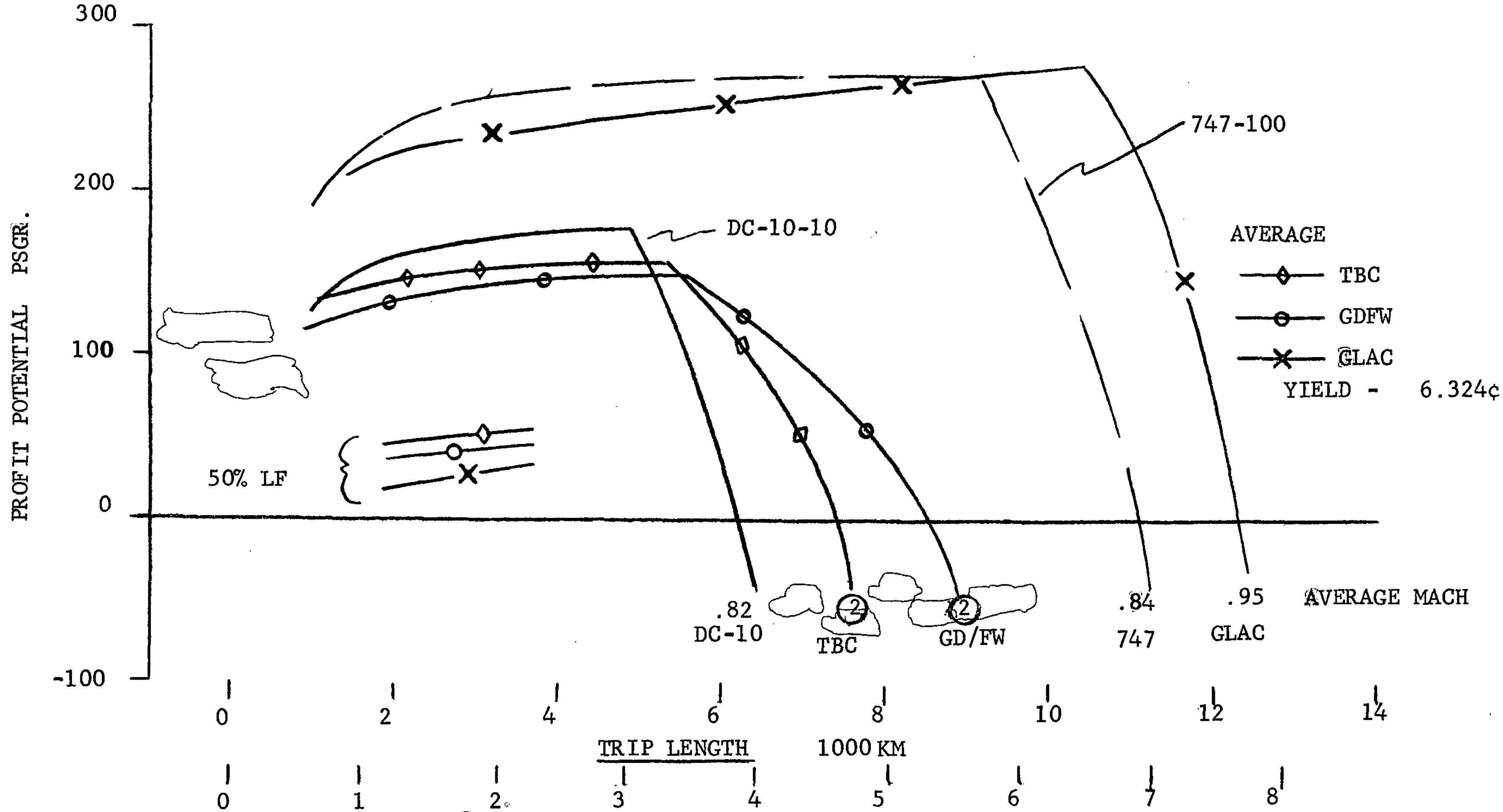


FIGURE 20

PROFIT POTENTIAL (1)
D.O.C.'S AS DEVELOPED BY
THE CONTRACTORS

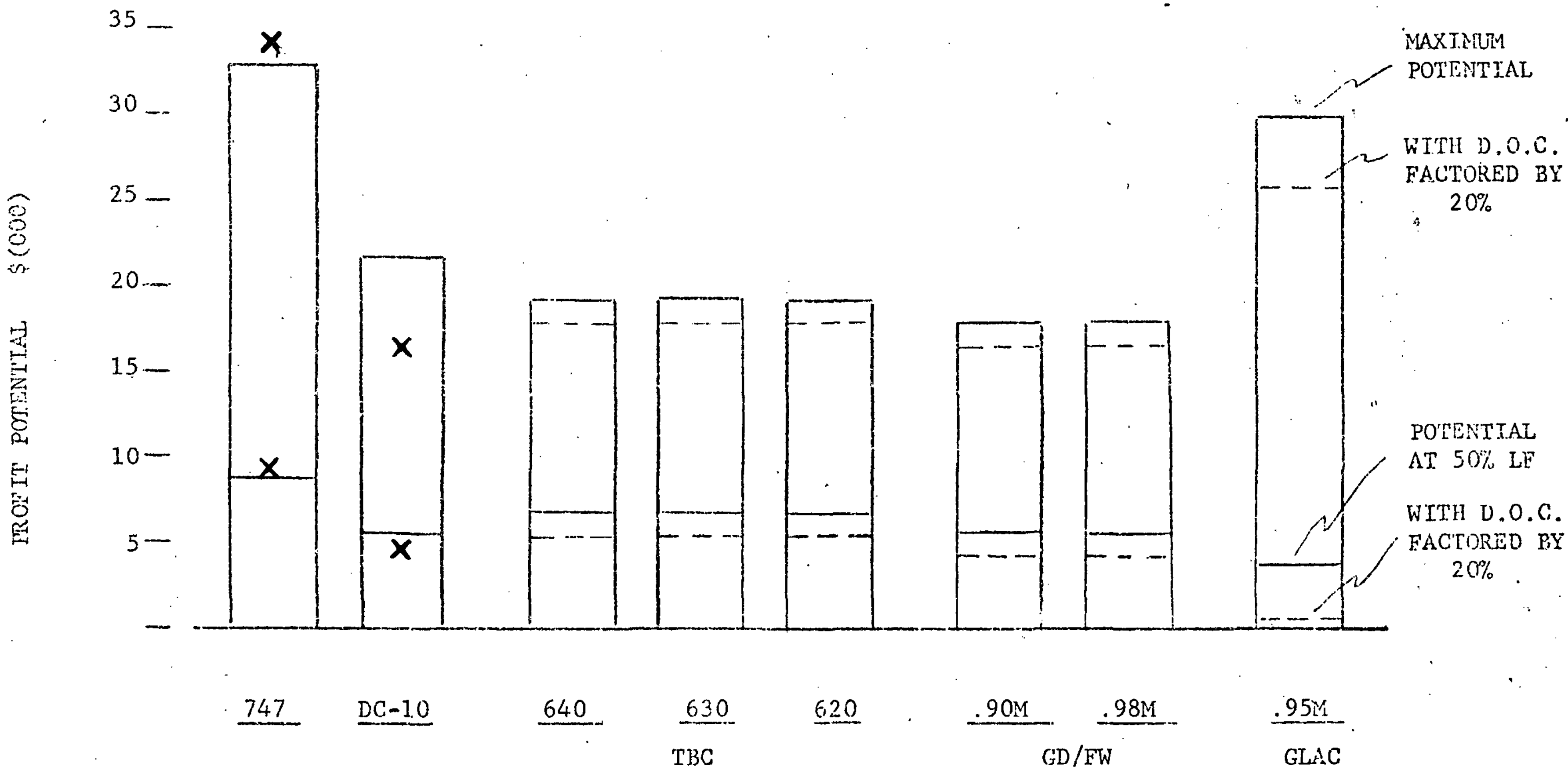


(1) (MAX. PSGR. POTENTIAL - BREAK EVEN PSGR) TRIP LENGTH 1000 ST. MI.

(2) AVERAGE OF THE THREE OR TWO CONFIGURATIONS

FIGURE 21
OPERATING PROFIT POTENTIAL
ASSUMED: 3218KM (2000 ST.MI.)
YIELD 6.324¢/RPM

(See TABLE 6)



× Simulated ATT Configuration
747 398 Seats
DC10 195 Seats

FIGURE 22

ADVANCED ENGINE COST IMPACT
(PRESENT TECHNOLOGY AIRFRAME MATERIALS)

(1972 $)

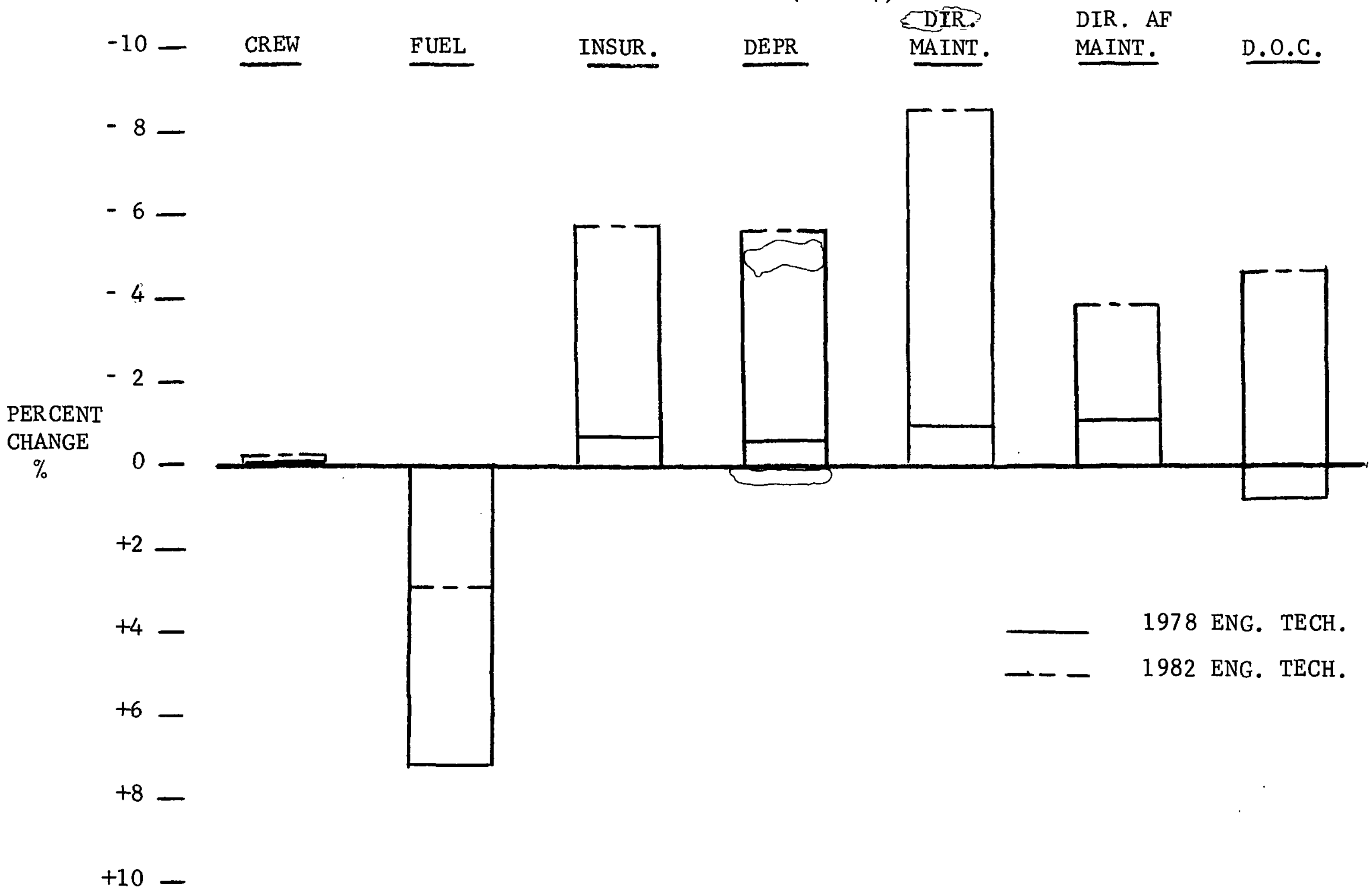


FIGURE 23

ADVANCED ENGINE COST IMPACT
(ADVANCED TECHNOLOGY AIRFRAME MATERIALS)

(1972 $)

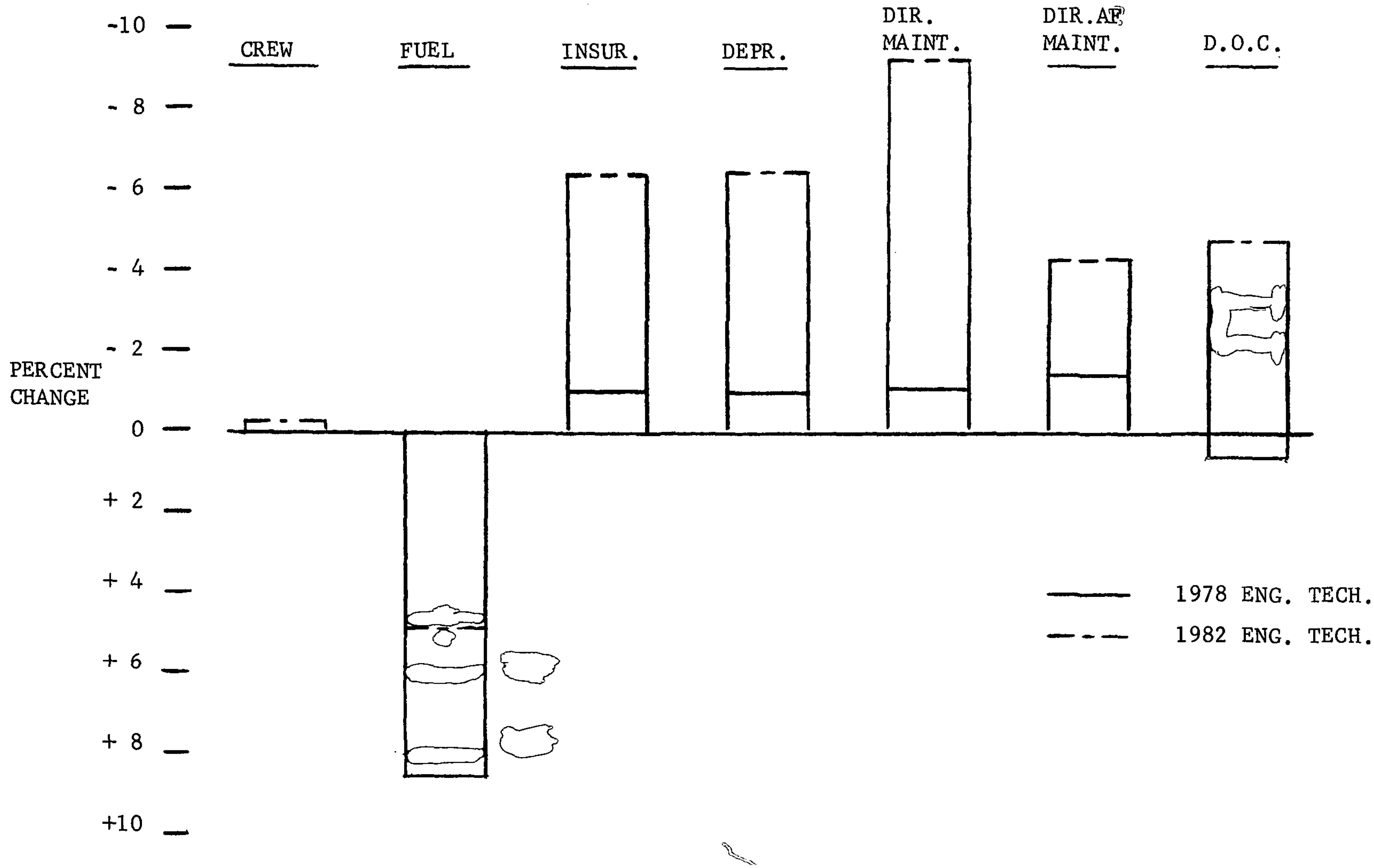
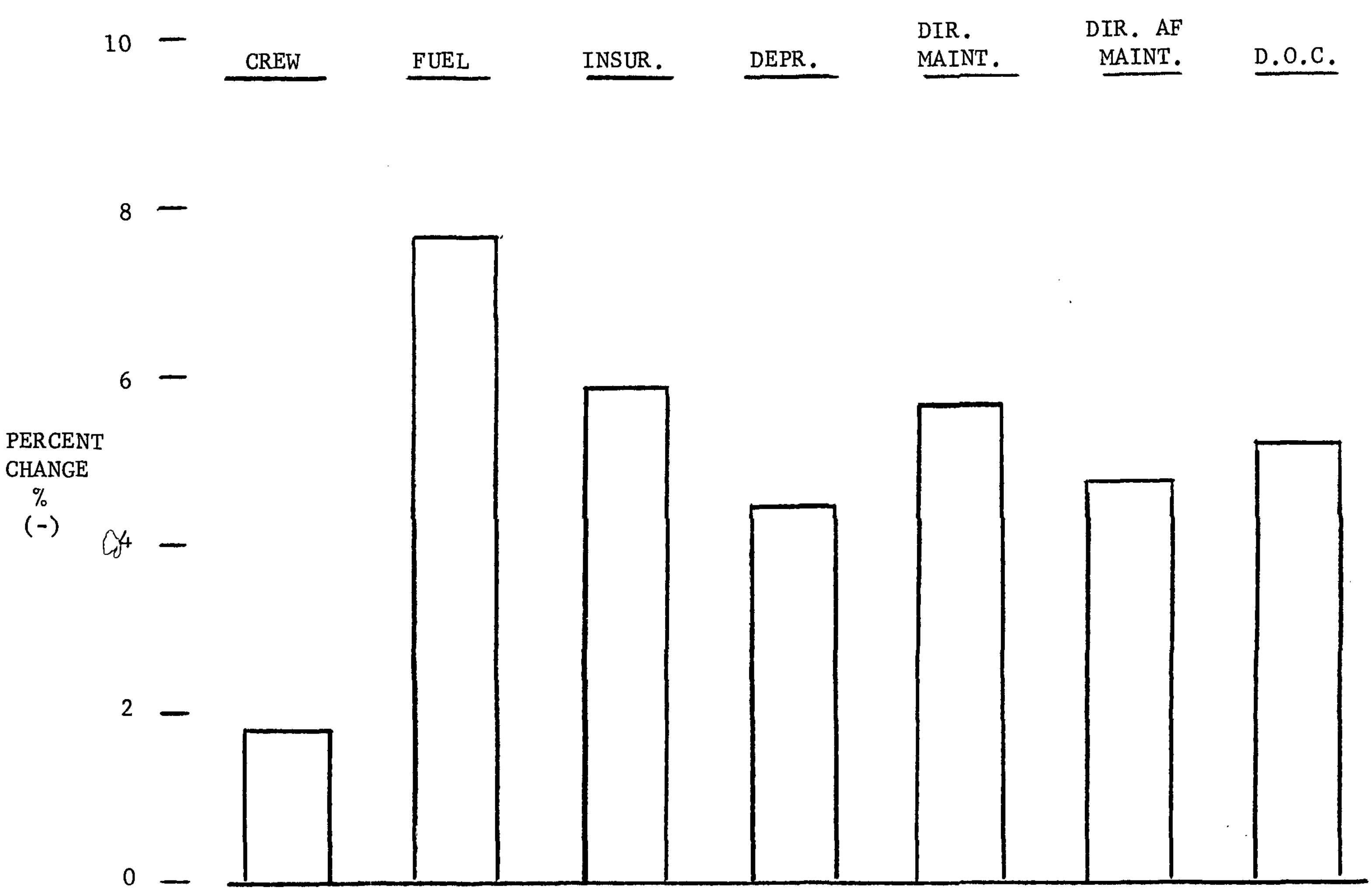


FIGURE 24

SUPERCRITICAL AIRFOIL COST IMPACT
(1972 $)



NOTE: PRESENT TECHNOLOGY MATERIALS

FIGURE 25

COMPOSITE STRUCTURE COST IMPACT
(1972 $)

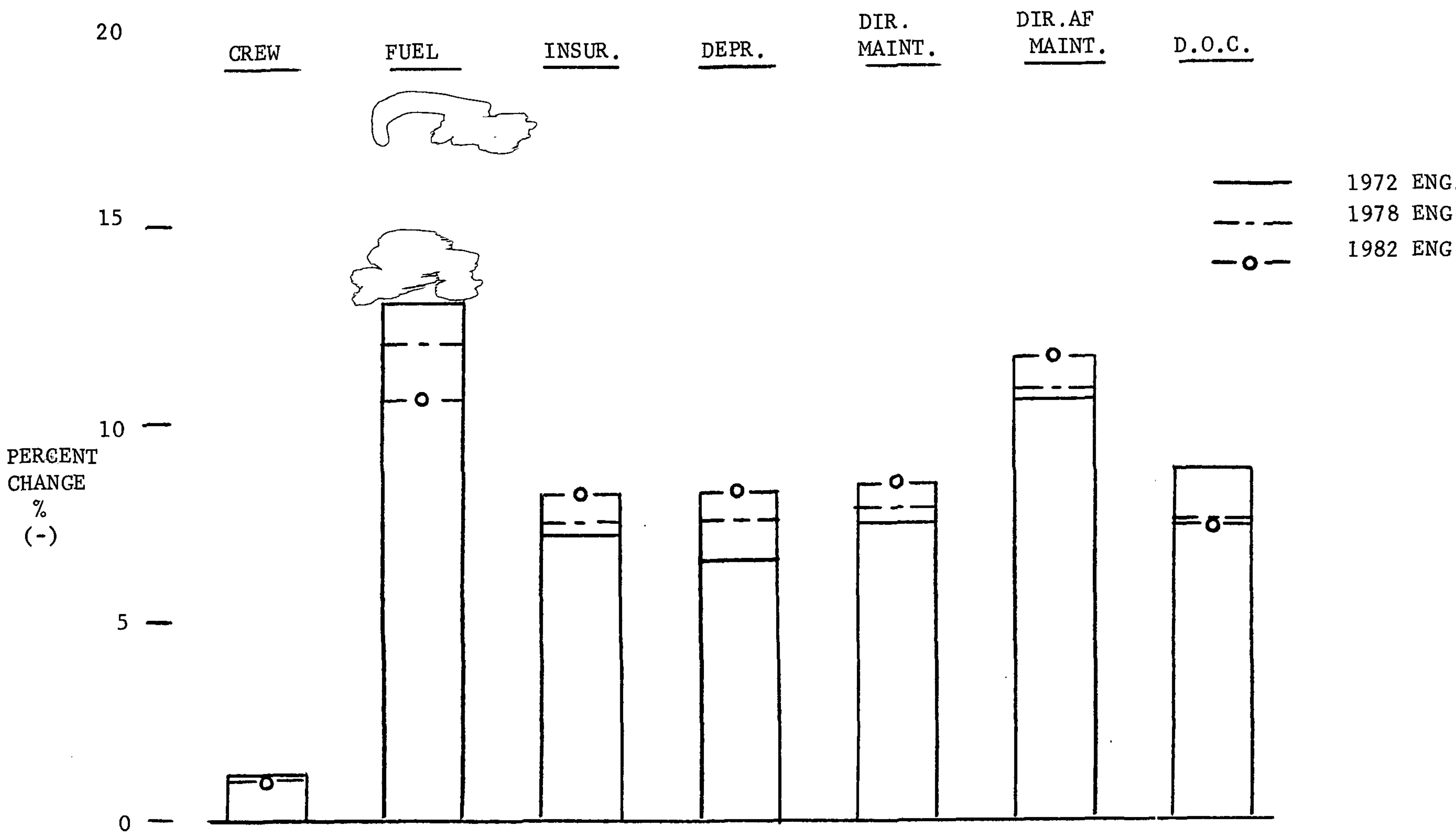


FIGURE 26

ACTIVE CONTROL SYSTEM COST IMPACT
(1972 $)

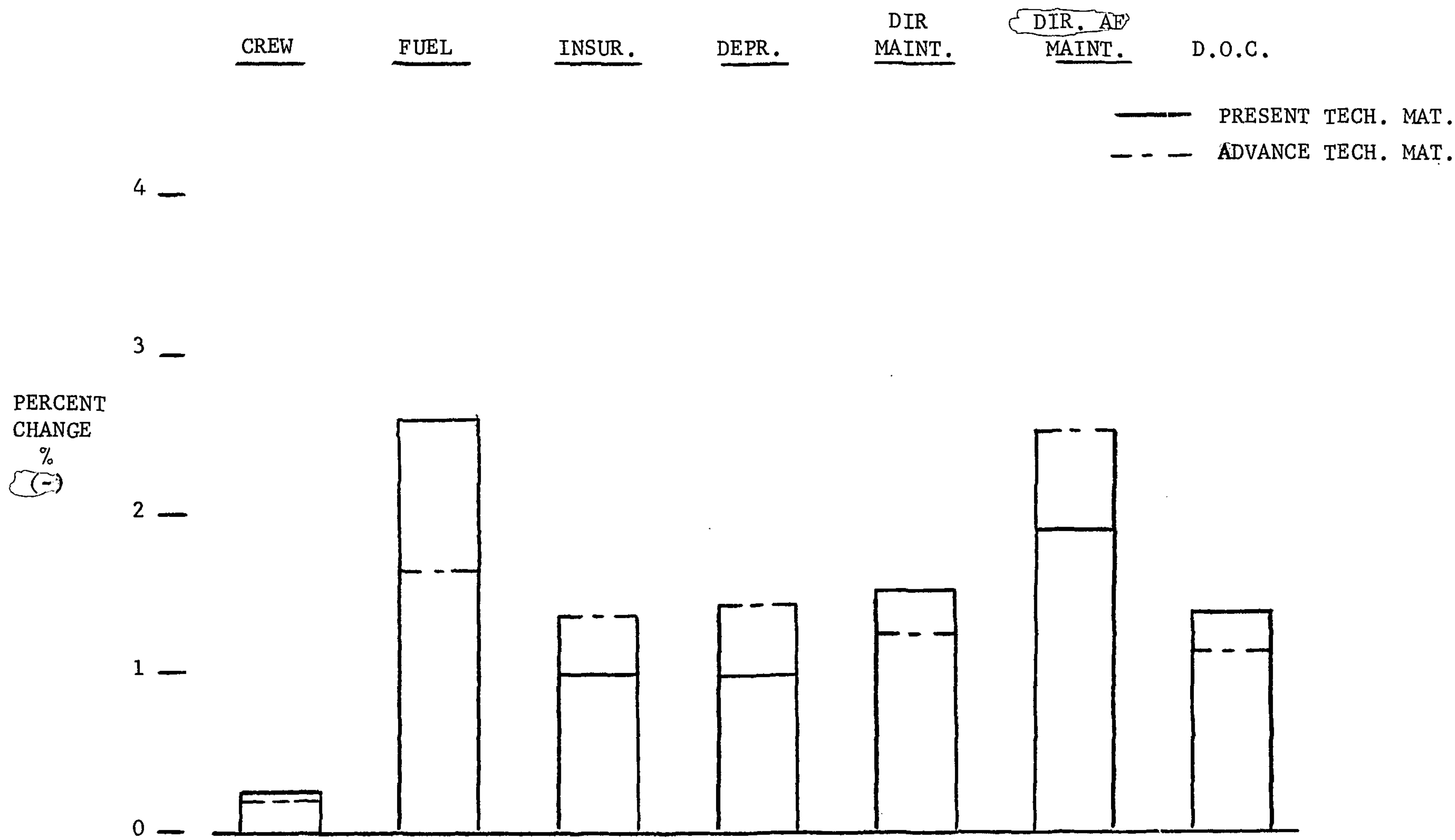


FIGURE C27

AGGREGATE TECHNOLOGY COST IMPACT

(MO.82 CONVENTIONAL - MO.90 ADVANCED TECHNOLOGY AIRCRAFT)

(1972 $)

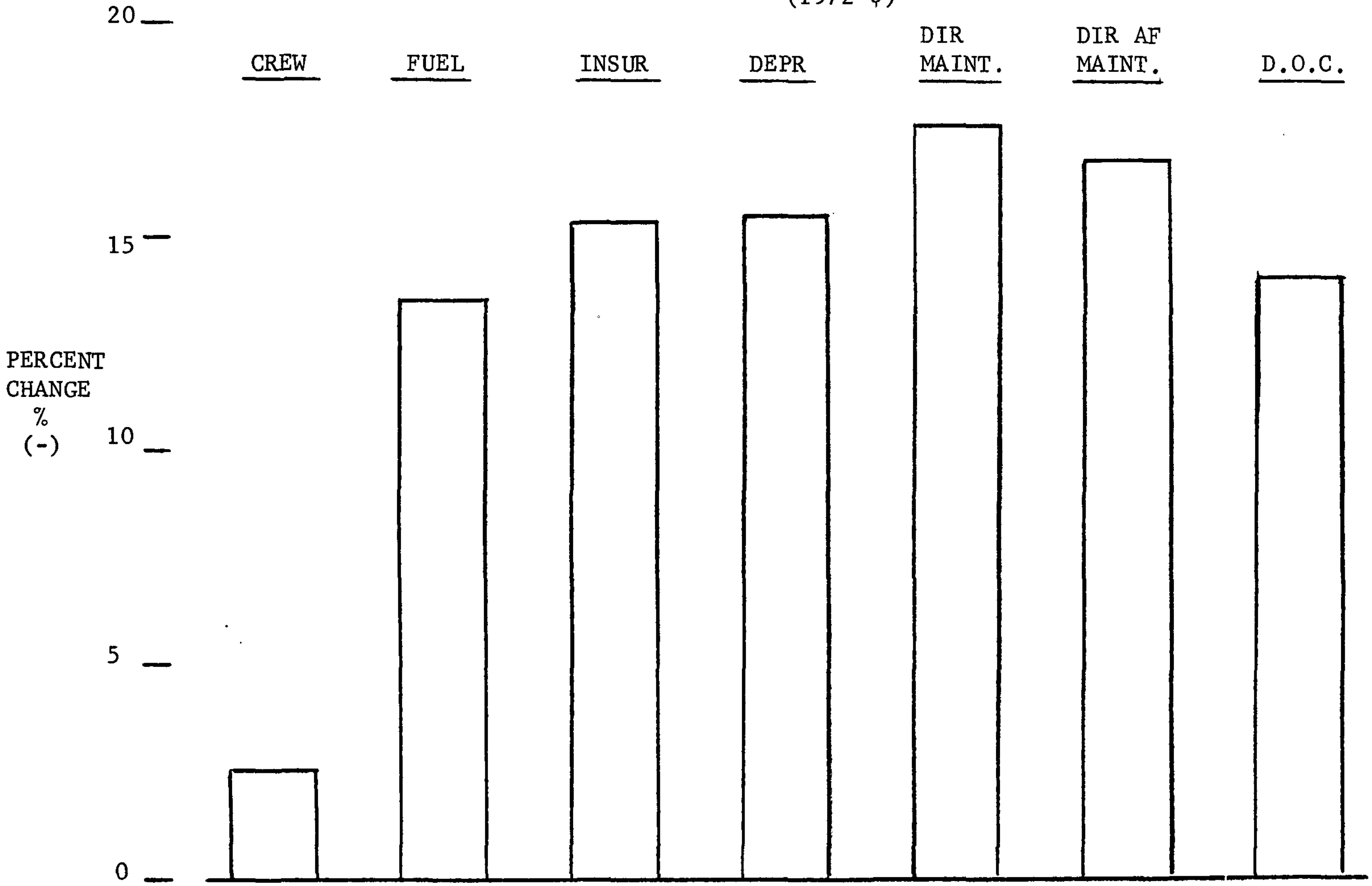


FIGURE 28

D.O.C. SUMMARY
ECONOMIC IMPACT OF ADVANCED TECHNOLOGIES

(1972 $)

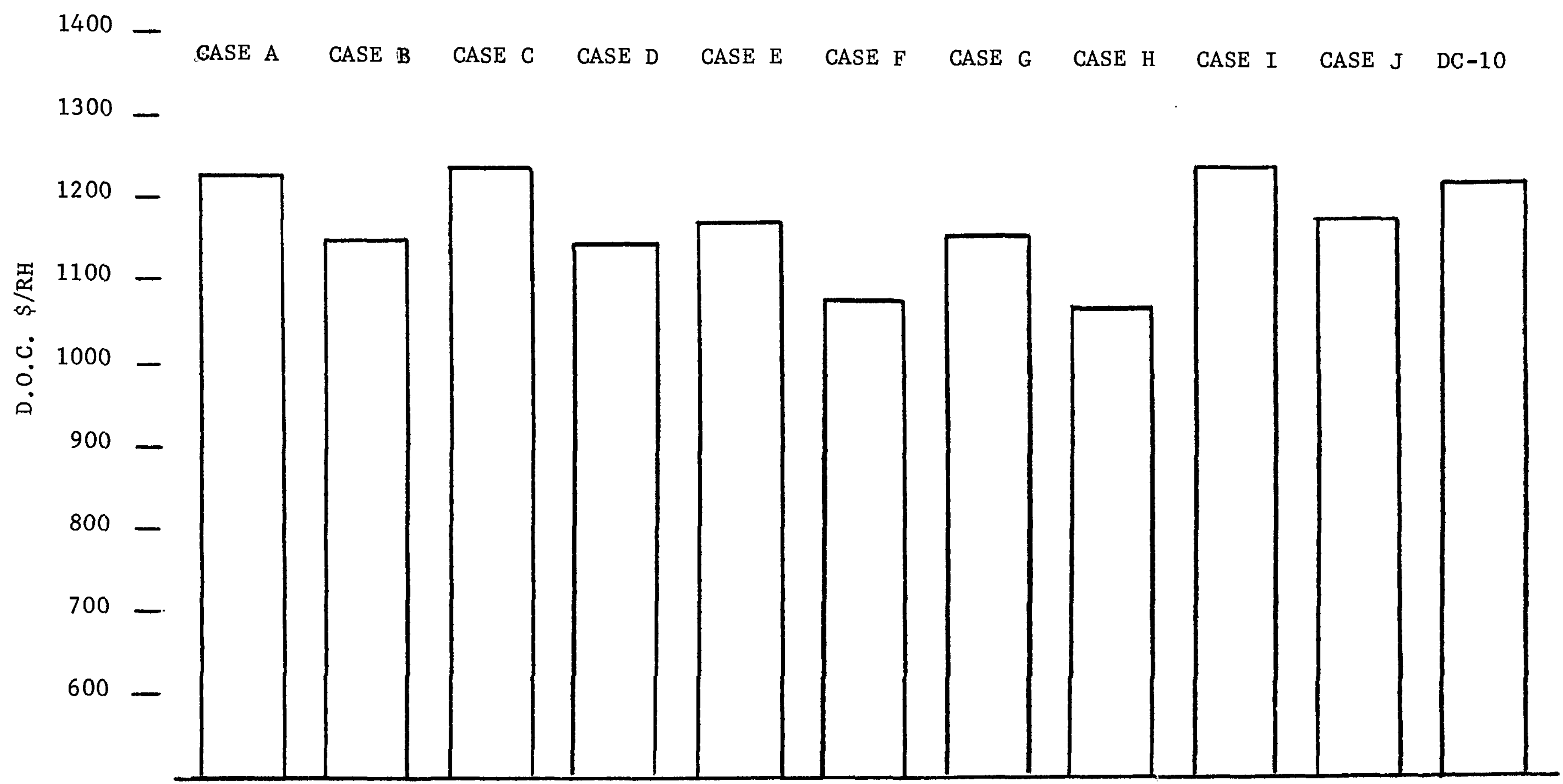


FIGURE 29

D.O.C. SUMMARY
ECONOMIC IMPACT OF ADVANCED TECHNOLOGIES

(1972 $)

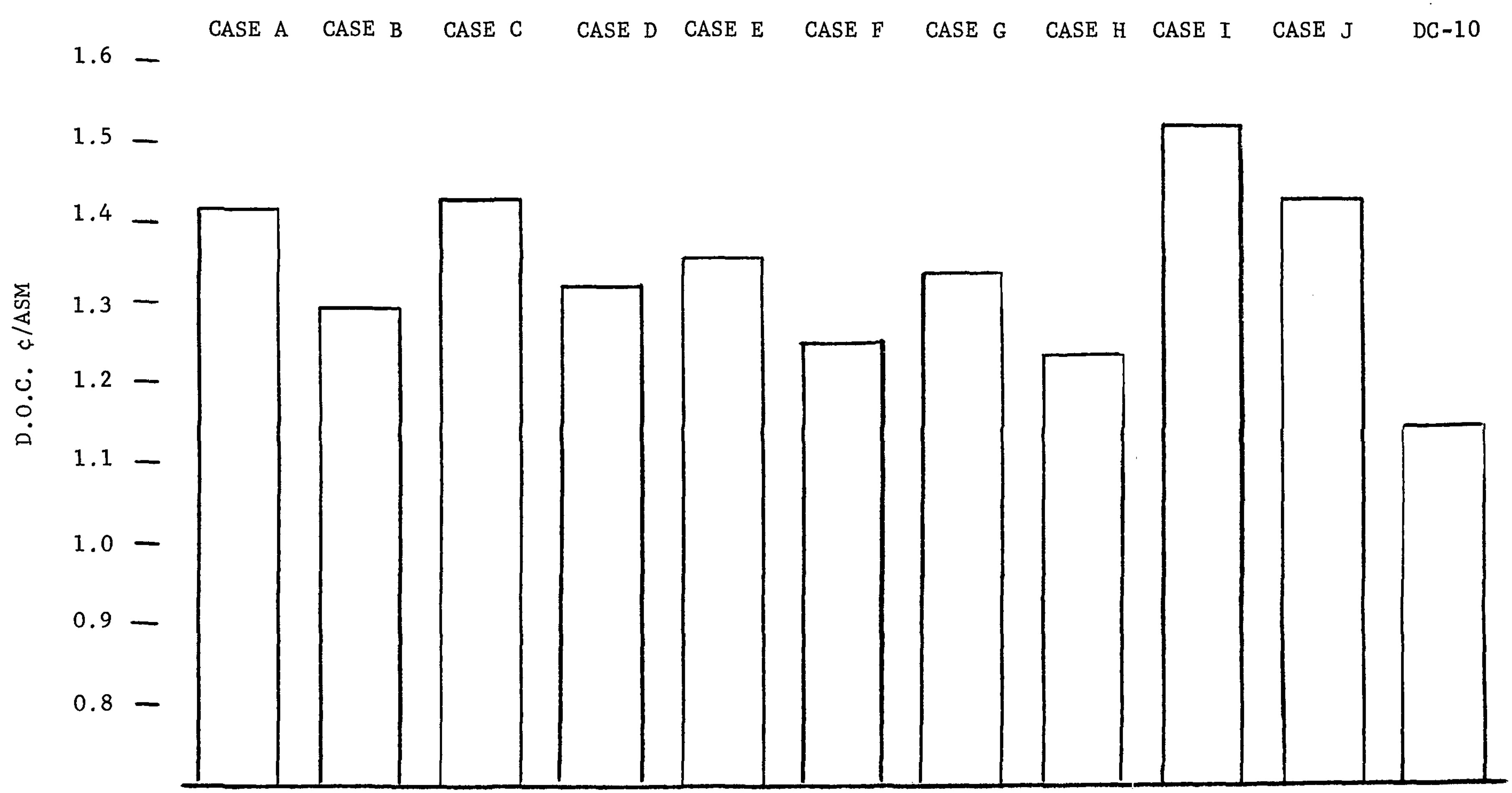


FIGURE 30

COMPOSITE STRUCTURE PROFIT IMPACT

(PRESENT TECHNOLOGY ENGINES - 1972)

(1972 $)

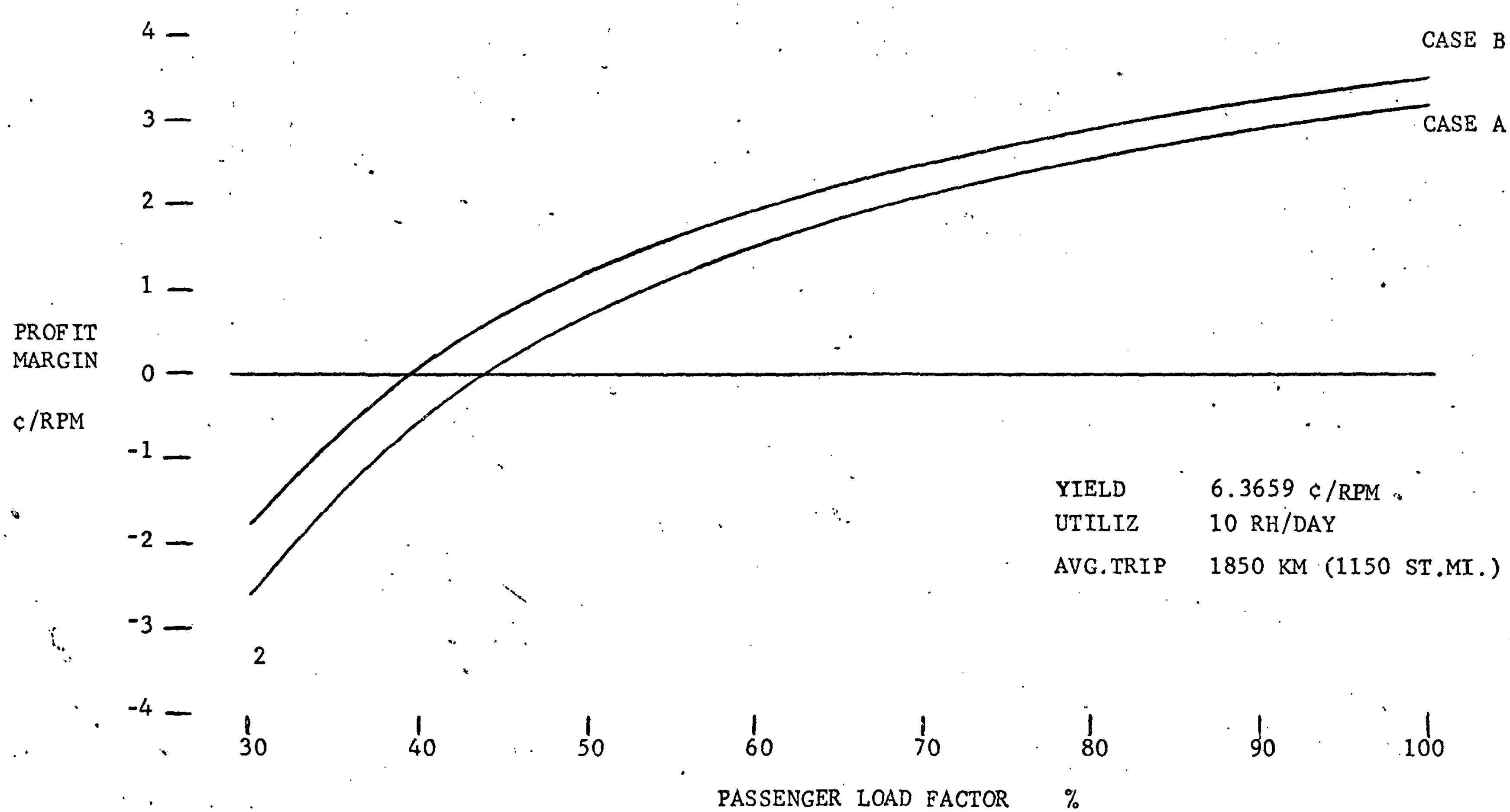


FIGURE 31

SUPERCRITICAL AIRFOIL PROFIT IMPACT

(PRESENT TECHNOLOGY AIRFRAME MATERIALS)

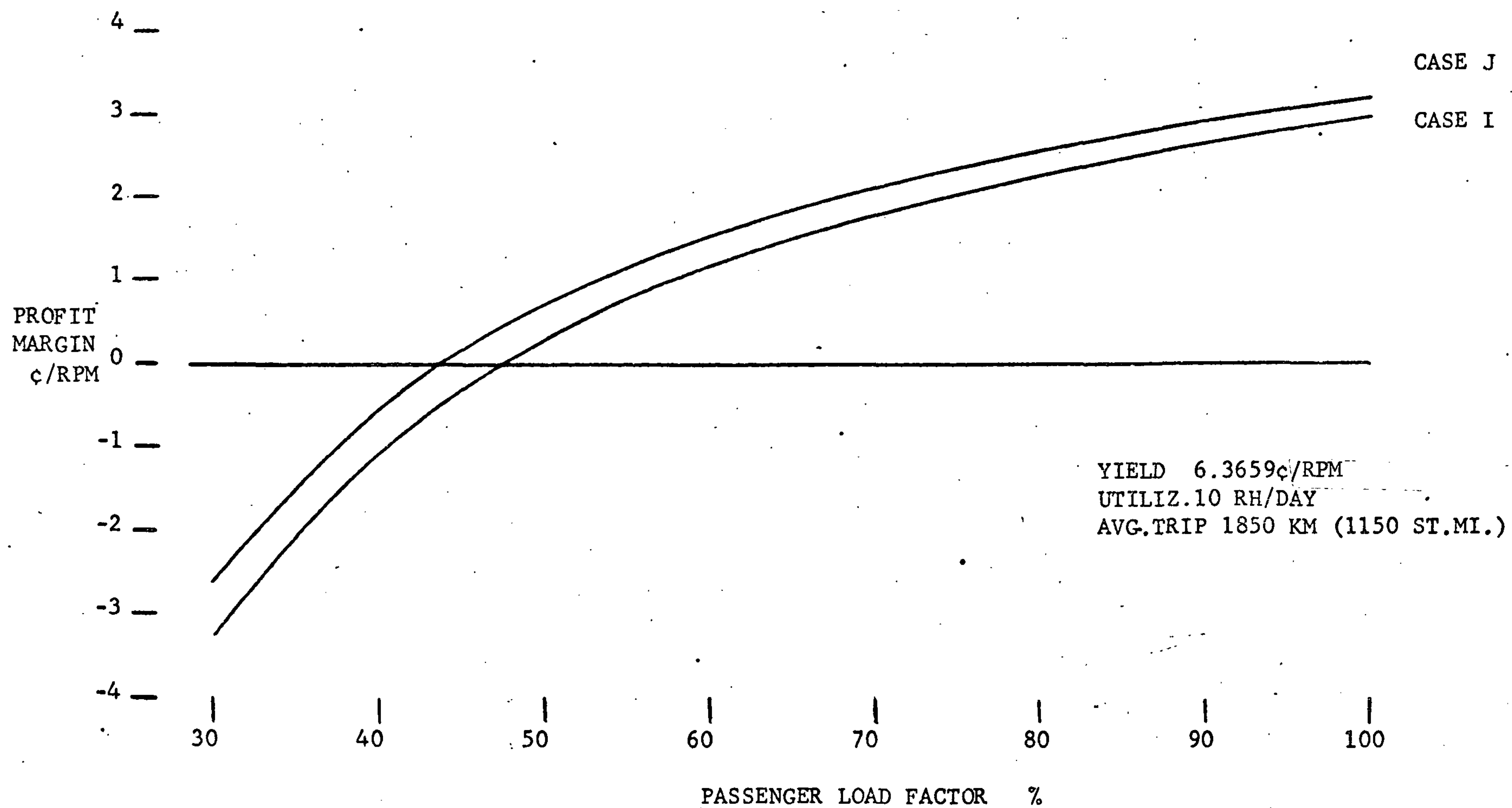


FIGURE 32

ACTIVE CONTROL SYSTEM PROFIT IMPACT
(PRESENT TECHNOLOGY AIRFRAME MATERIALS)
(1972 $)

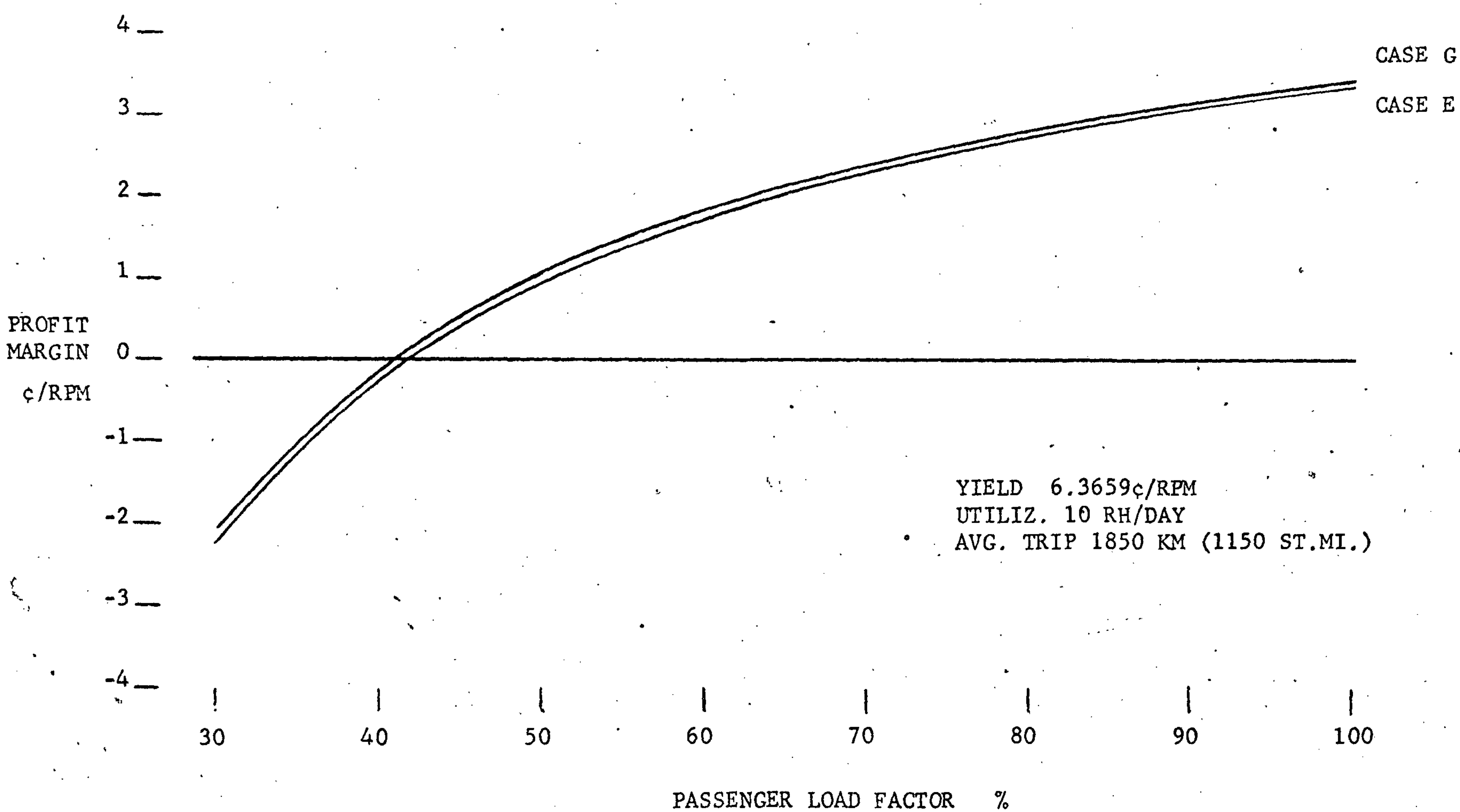


FIGURE 33

AGGREGATE TECHNOLOGY PROFIT IMPACT

(1972 $)

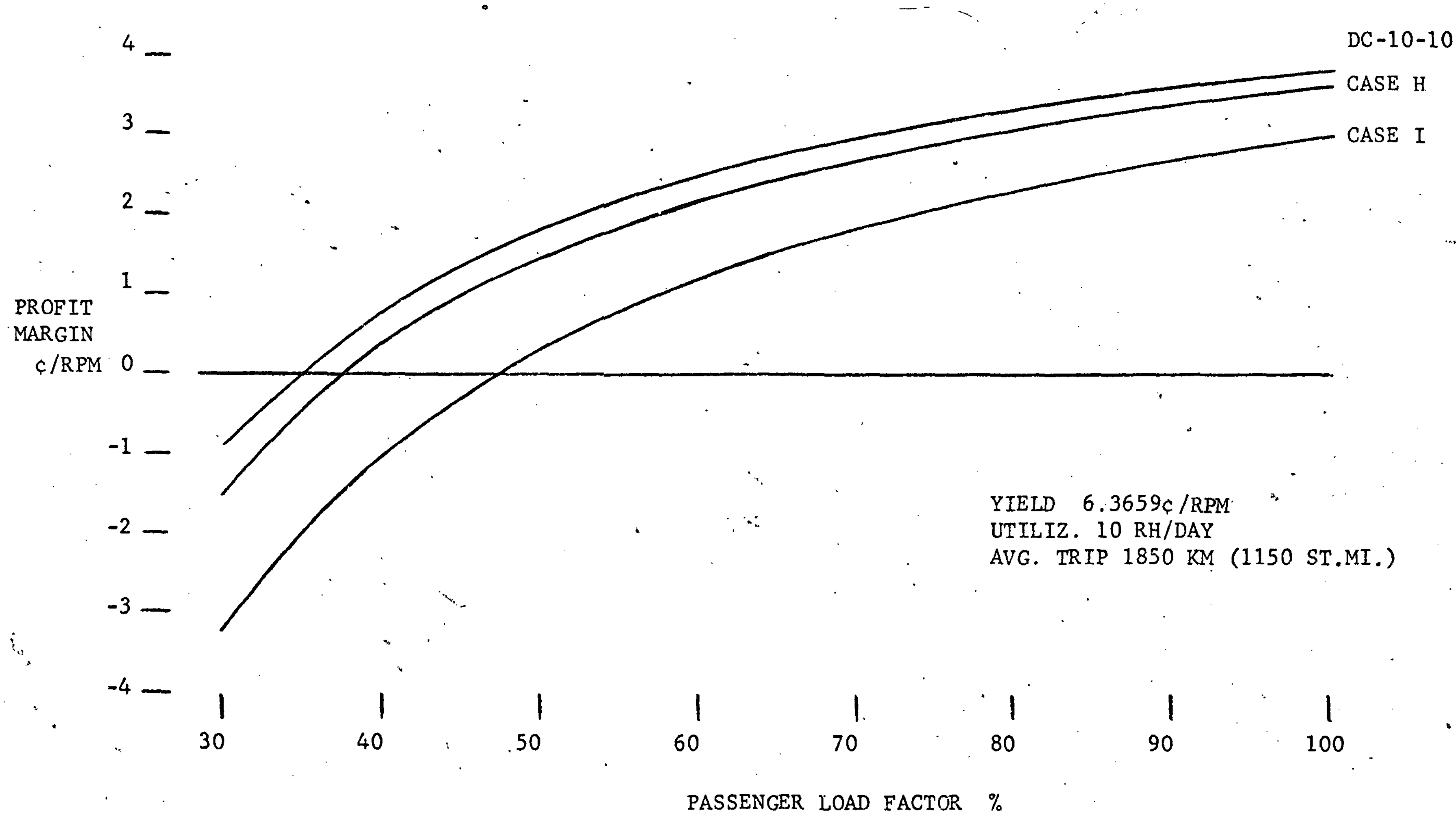
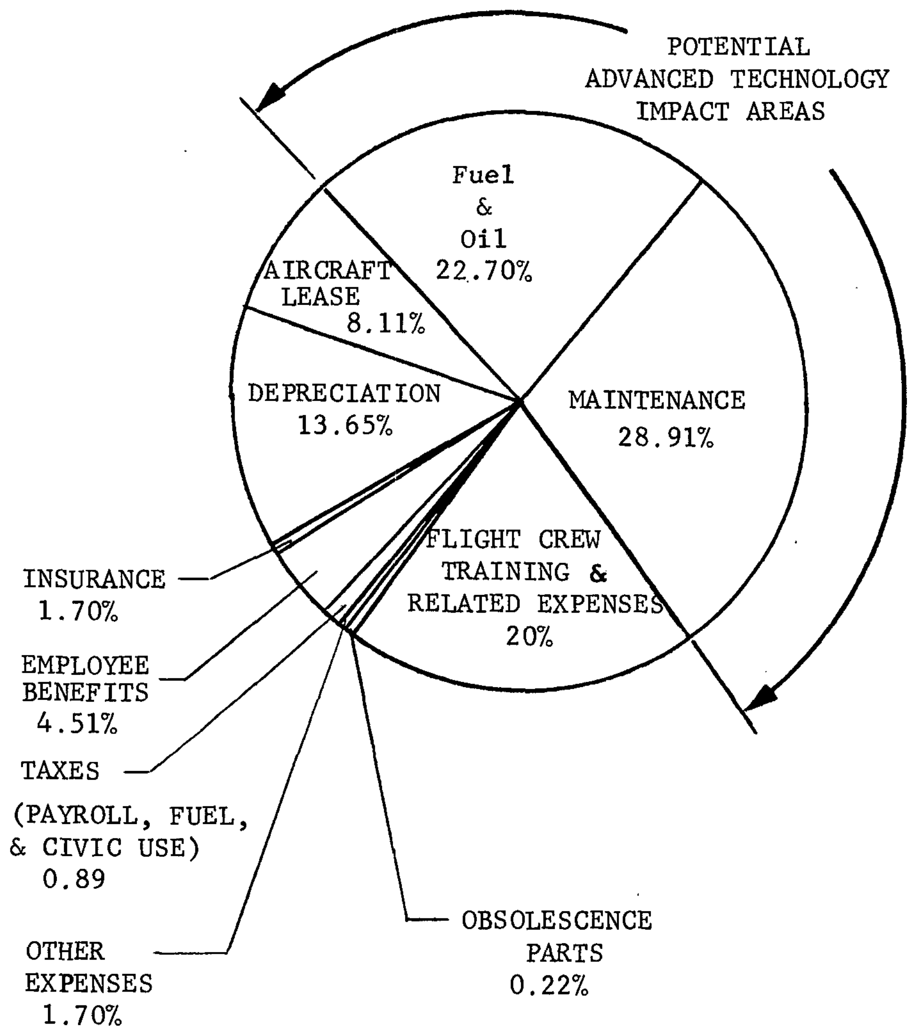
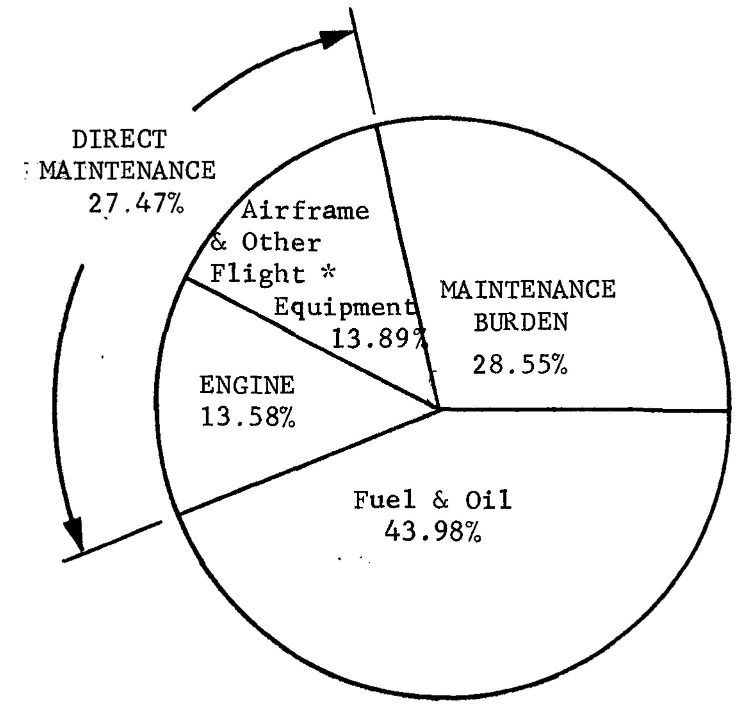


FIGURE 34
DIRECT OPERATING COSTS
(1972)

DISTRIBUTION OF
OPERATING COST



DISTRIBUTION OF POTENTIAL ADVANCED
TECHNOLOGY COST IMPACT AREAS



* 7.2% of Total D.O.C.

FIGURE 3.5
OPERATING COST SUMMARY
(1972 $)

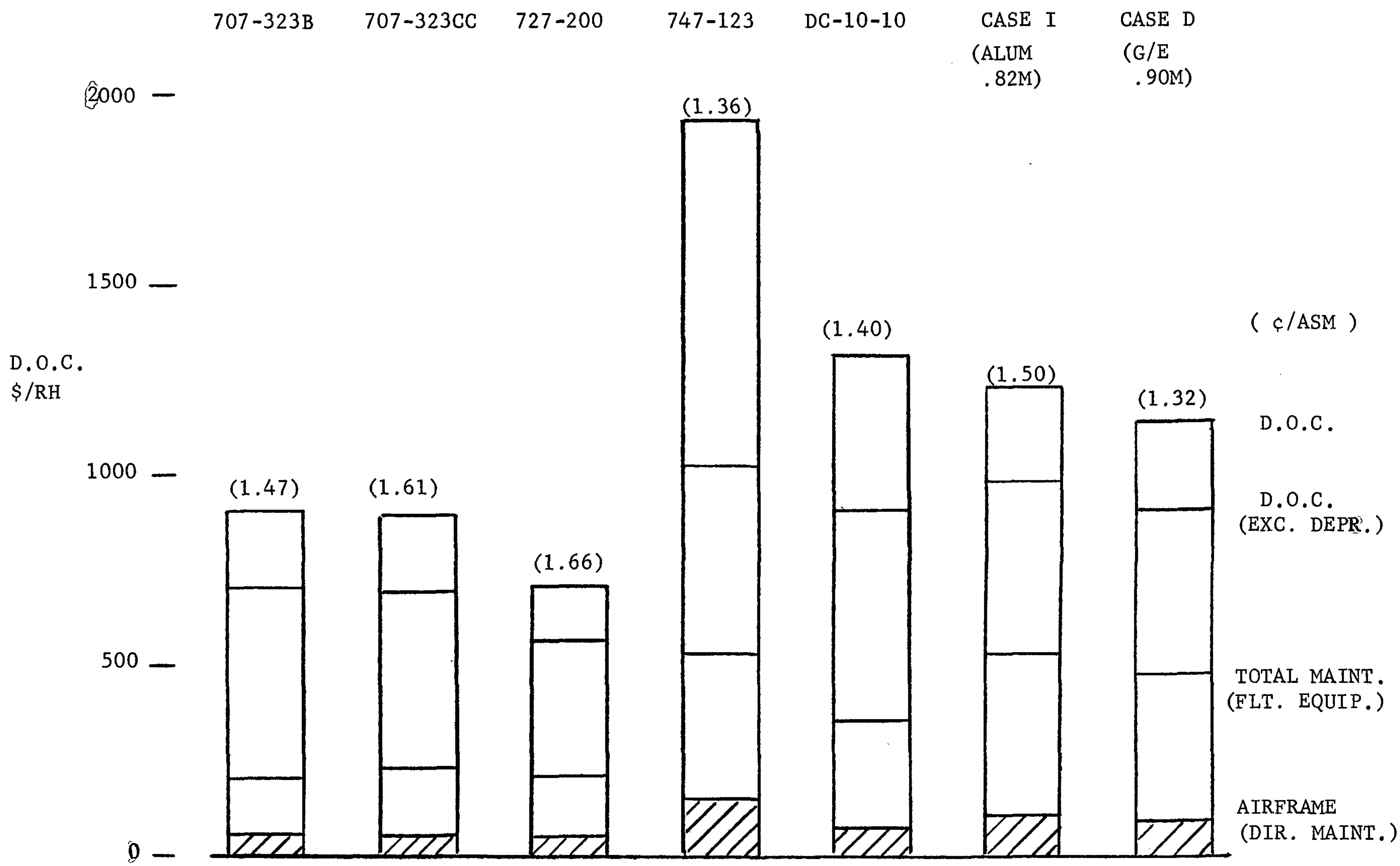
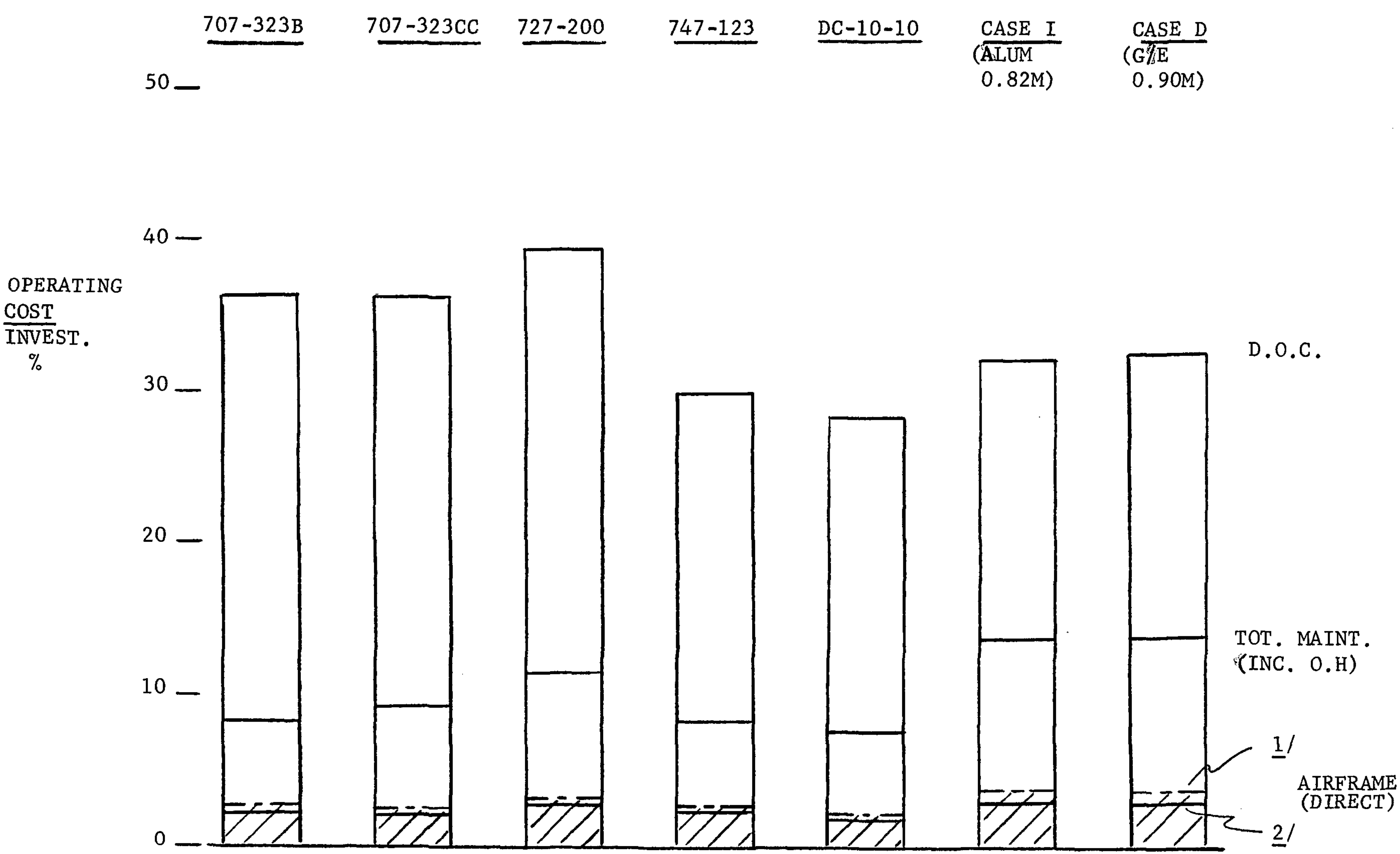


FIGURE 36

OPERATING COST PER INVESTMENT $

(1972 $)



1/ AF COST/UNIT AF INVEST.
2/ AF COST/FLYAWAY PRICE

FIGURE 37

AIRFRAME MATERIAL COST SUMMARY

SAMPLE OF PRIMARY & SECONDARY TECHNOLOGY IMPACT AREAS

(EXPENSE CATEGORY AS PERCENT OF SAMPLE)

1972

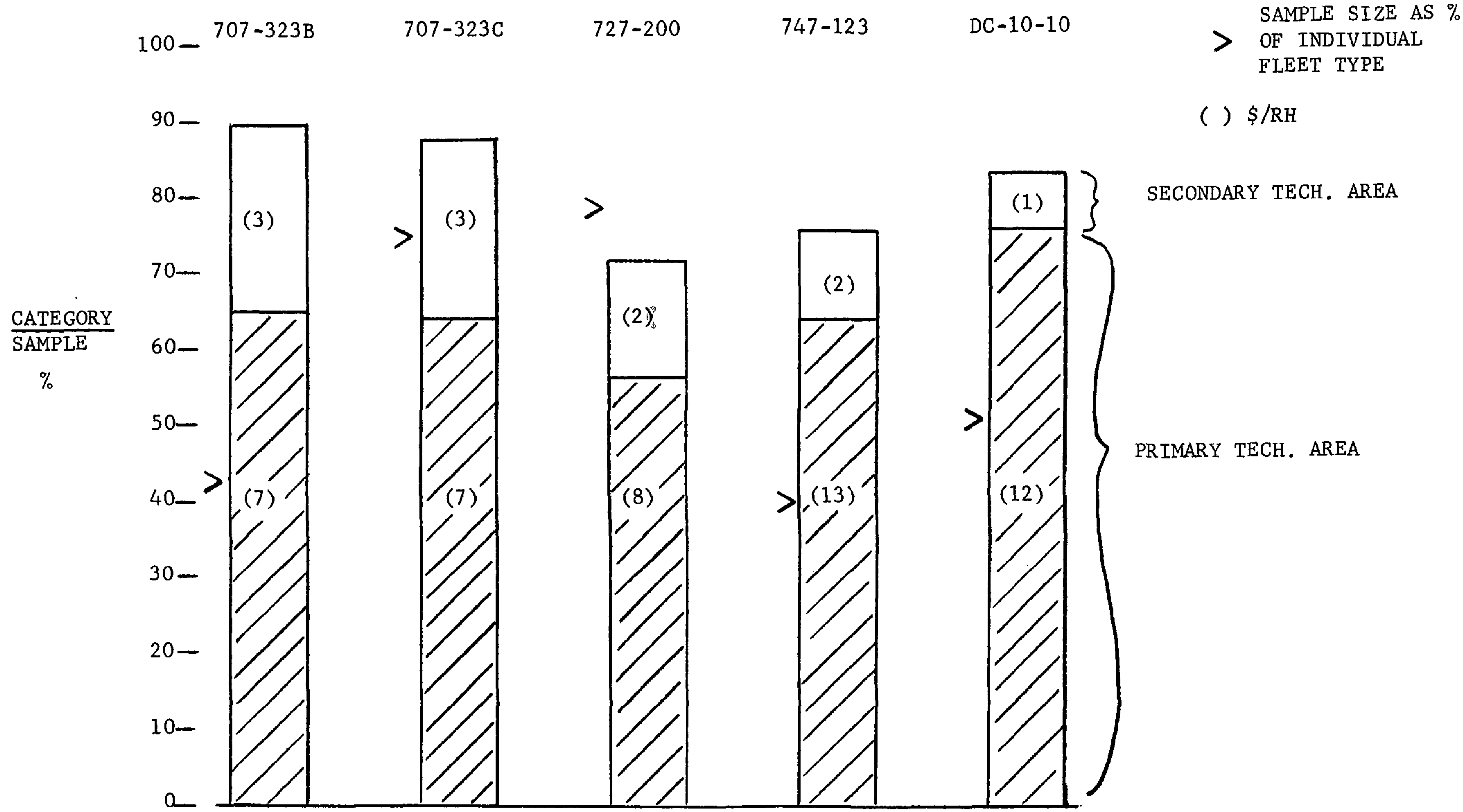


FIGURE 38

AIRFRAME LABOR REQUIREMENT SUMMARY
SAMPLE OF PRIMARY & SECONDARY TECHNOLOGY IMPACT AREAS
(EXPENSE CATEGORY AS PERCENT OF SAMPLE)
1972

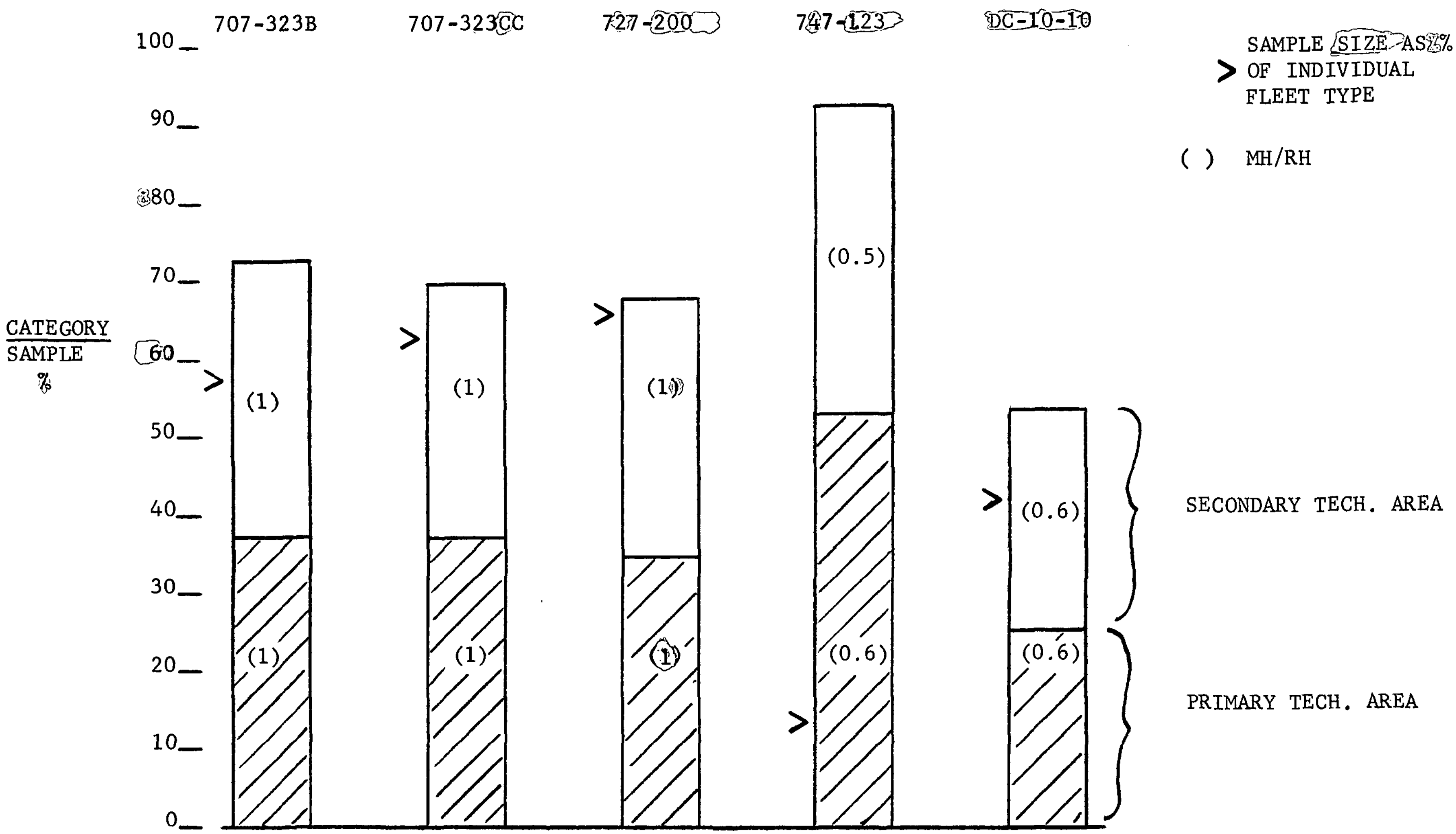


FIGURE 39

DIRECT AIRFRAME MAINTENANCE COST SUMMARY

SAMPLE OF PRIMARY & SECONDARY TECHNOLOGY IMPACT AREAS (EXPENSE CATEGORY AS PERCENT OF SAMPLE) (1972)

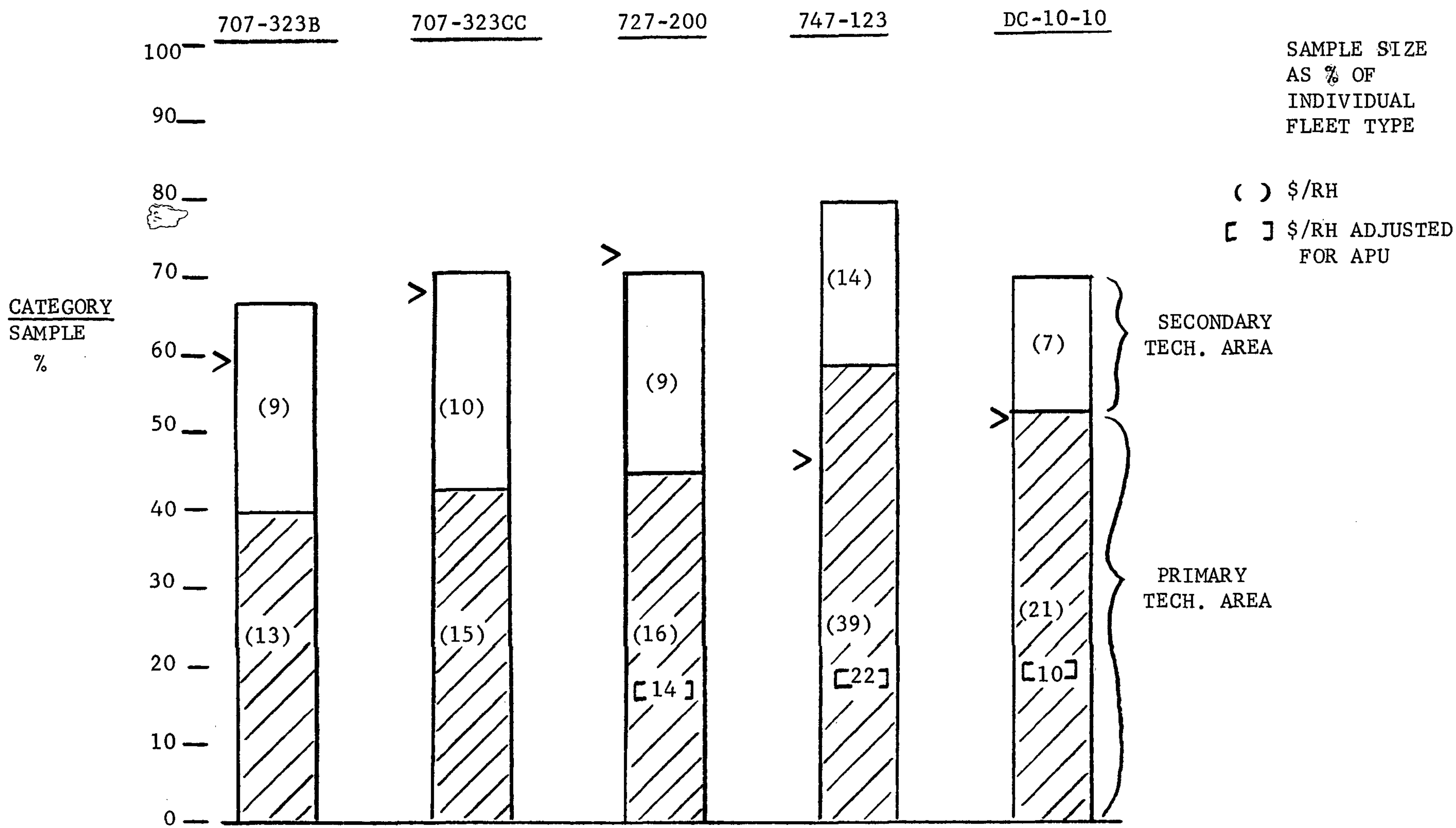


FIGURE 40

POTENTIAL ADVANCED TECHNOLOGY STUDY AREAS

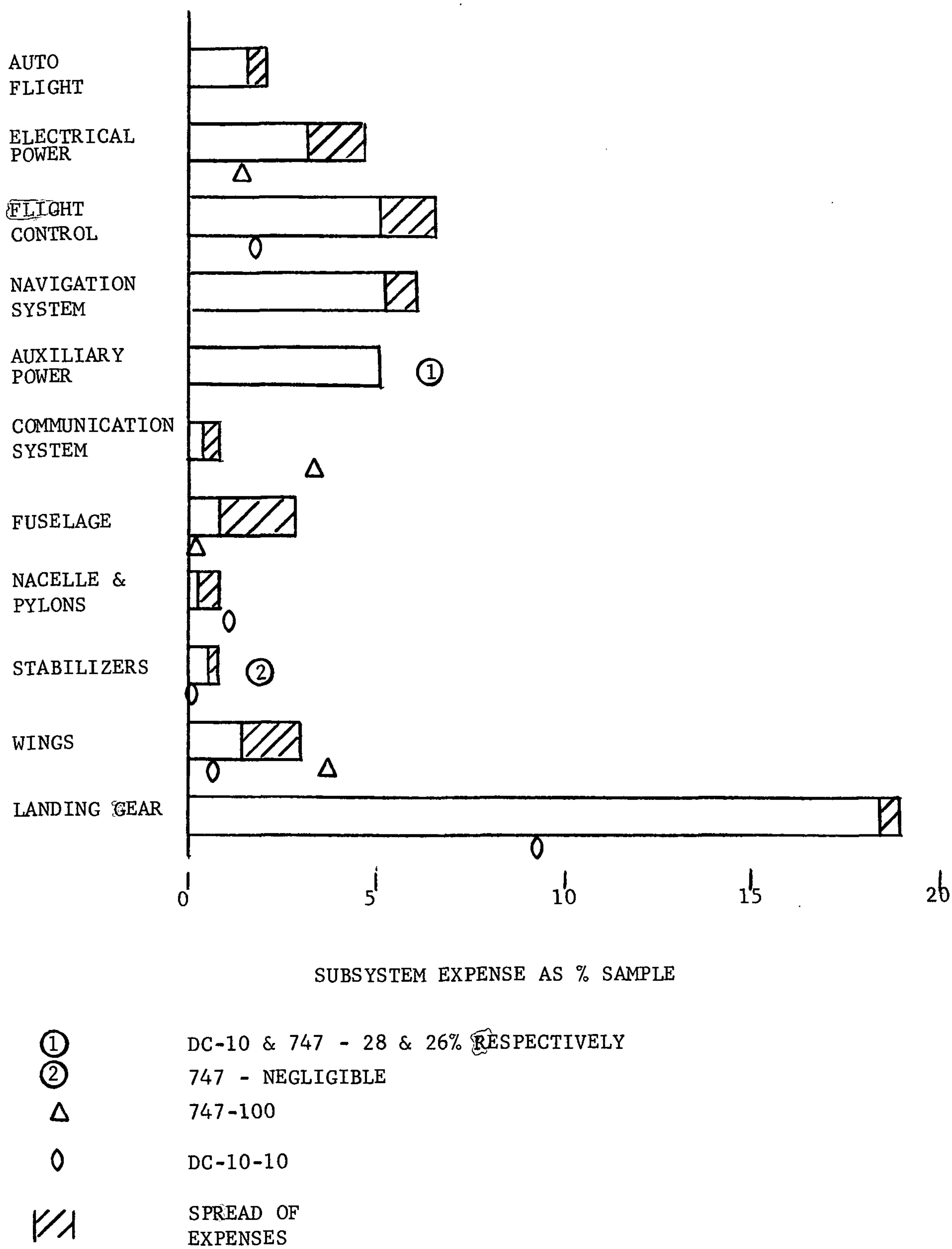


FIGURE 41
CONVENTIONAL AIRCRAFT
FLYAWAY PRICE
(1972 $)

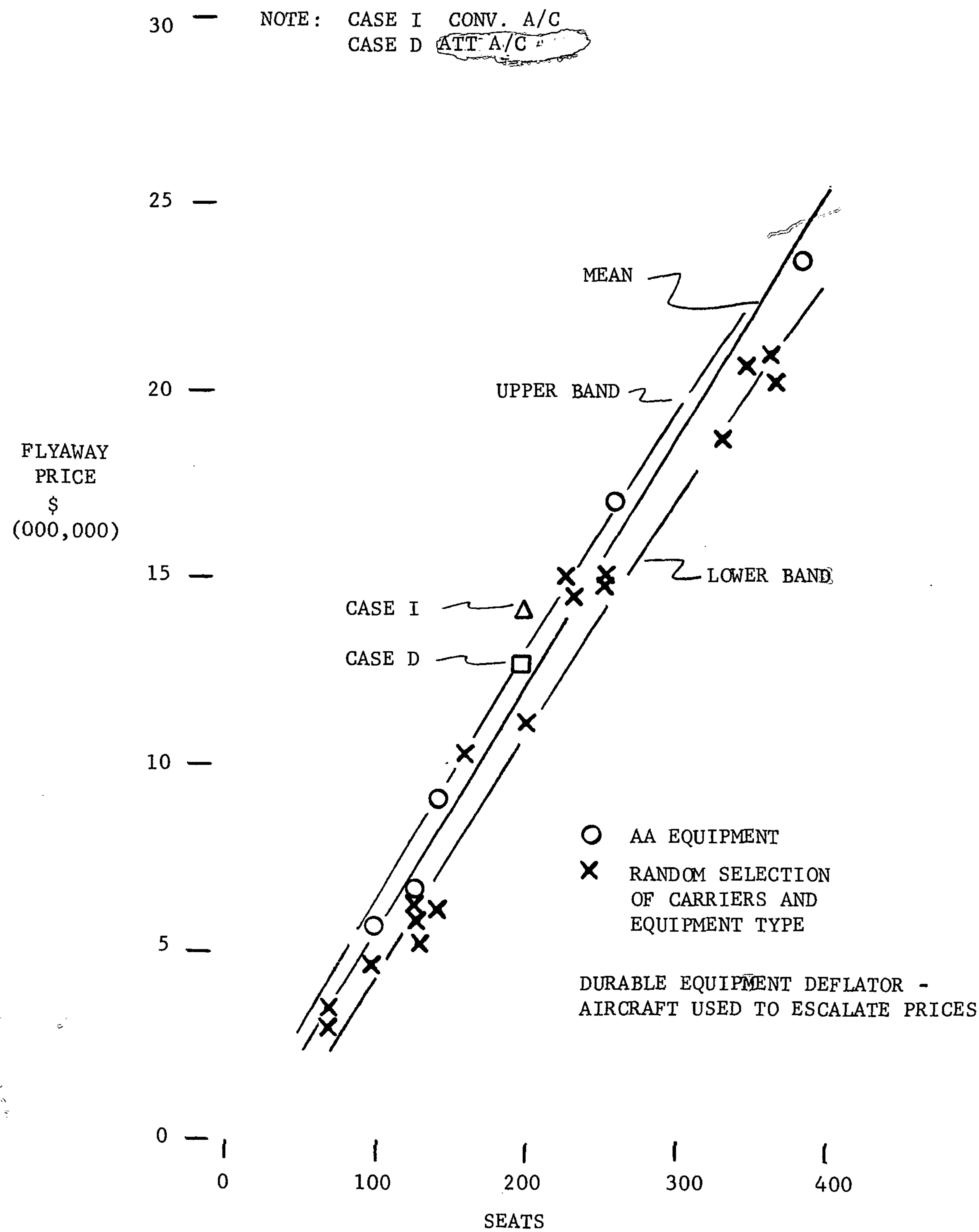


FIGURE 42
CONVENTIONAL AIRCRAFT
GENERAL RELATIONSHIPS

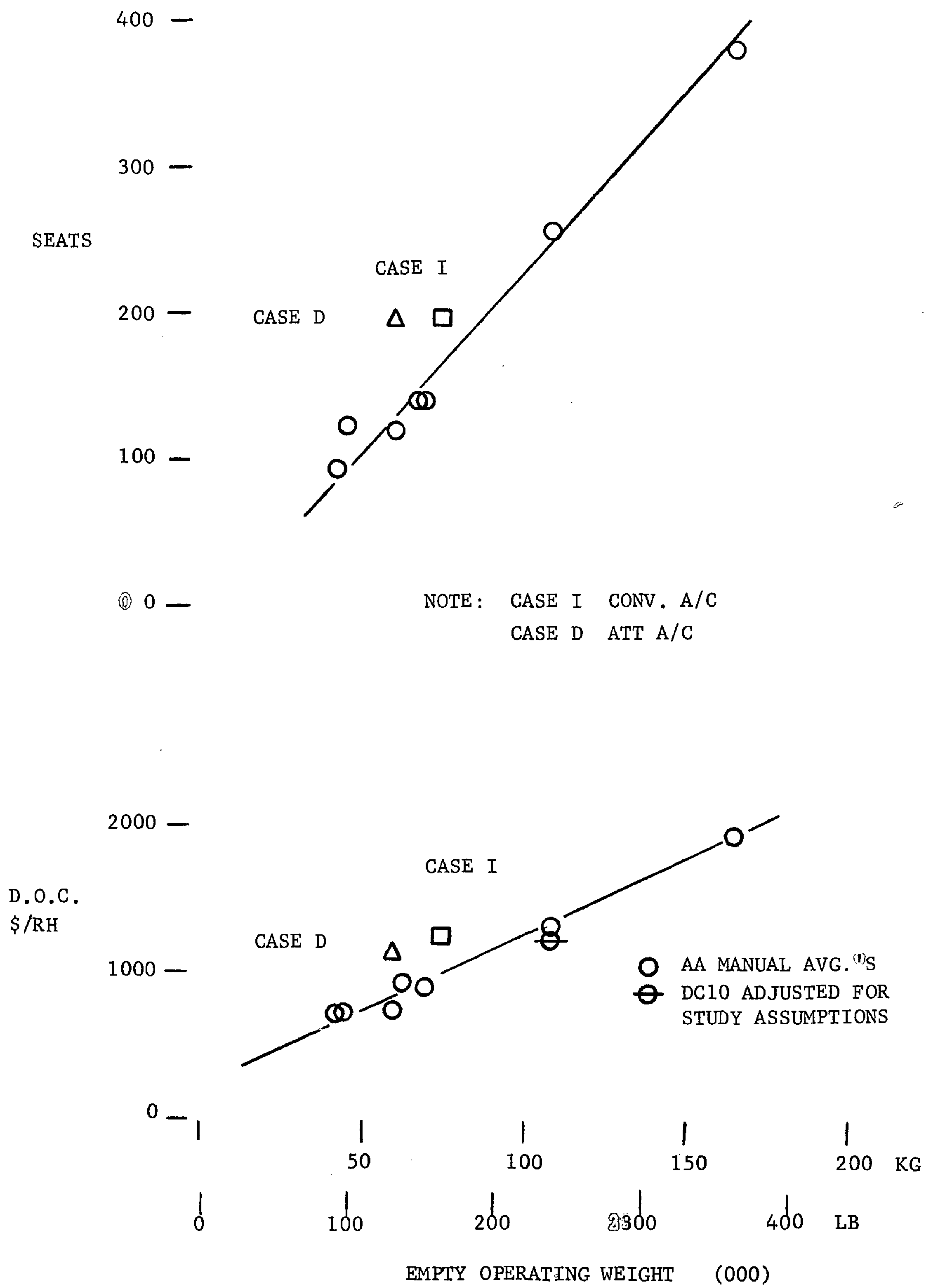


FIGURE 43
CONVENTIONAL AIRCRAFT
(GENERAL EXPENSE AND INVESTMENT RELATIONSHIPS)

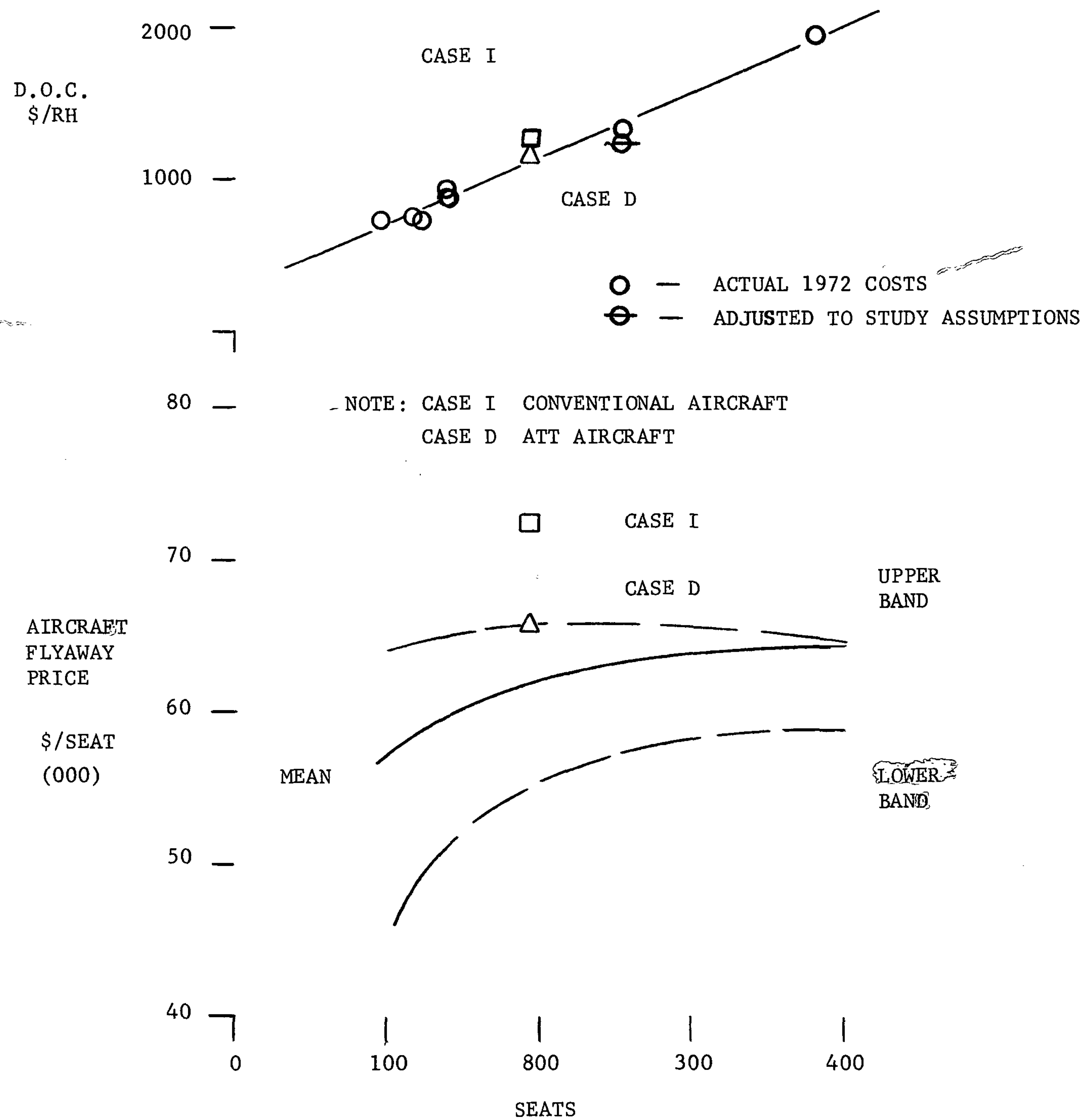


FIGURE 44
CONVENTIONAL AND ADVANCED
TECHNOLOGY COMPARISONS
(195 SEATS)

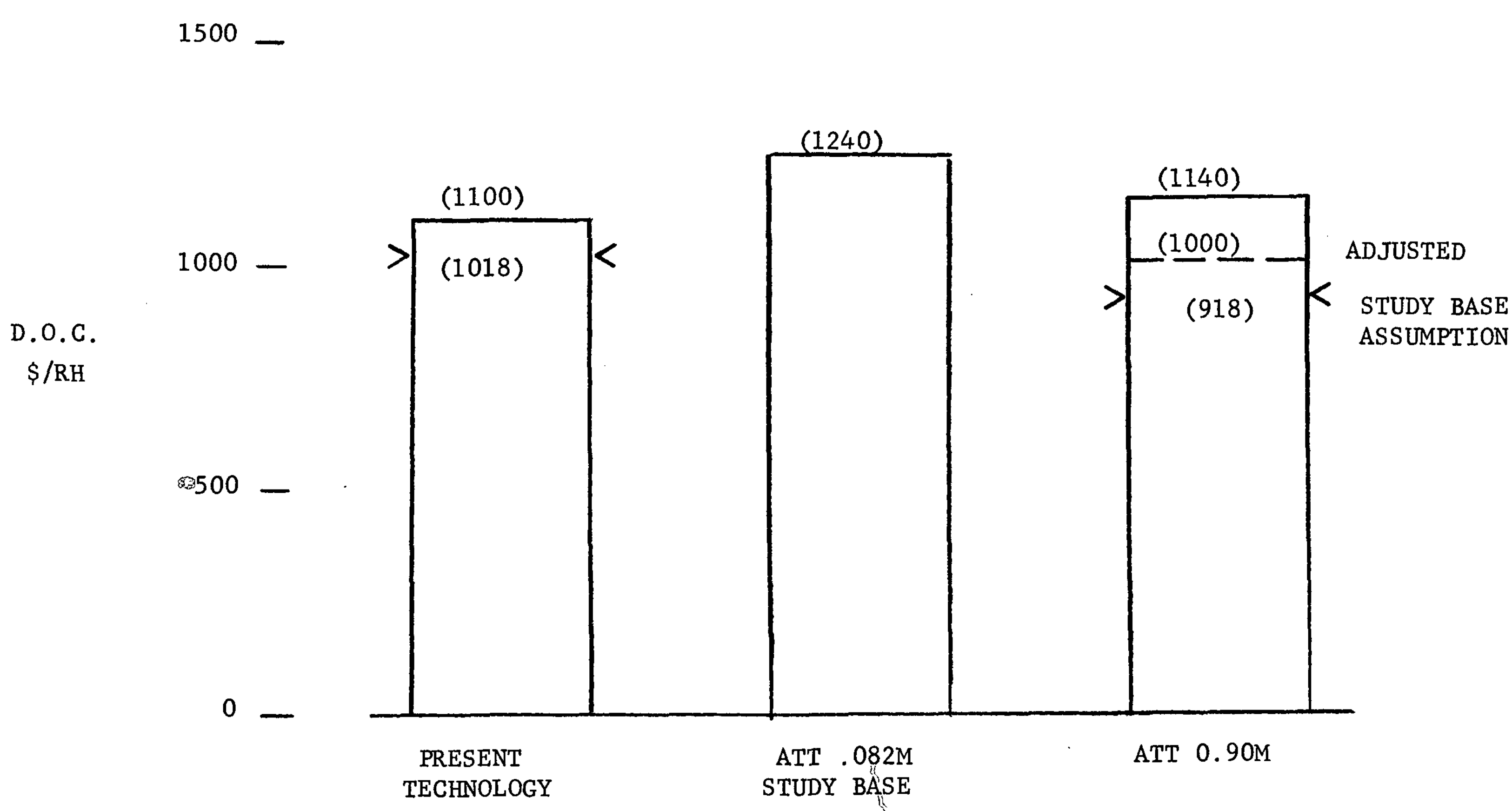


FIGURE 45
CONVENTIONAL AND ADVANCED
TECHNOLOGY COMPARISONS
(195 SEATS)

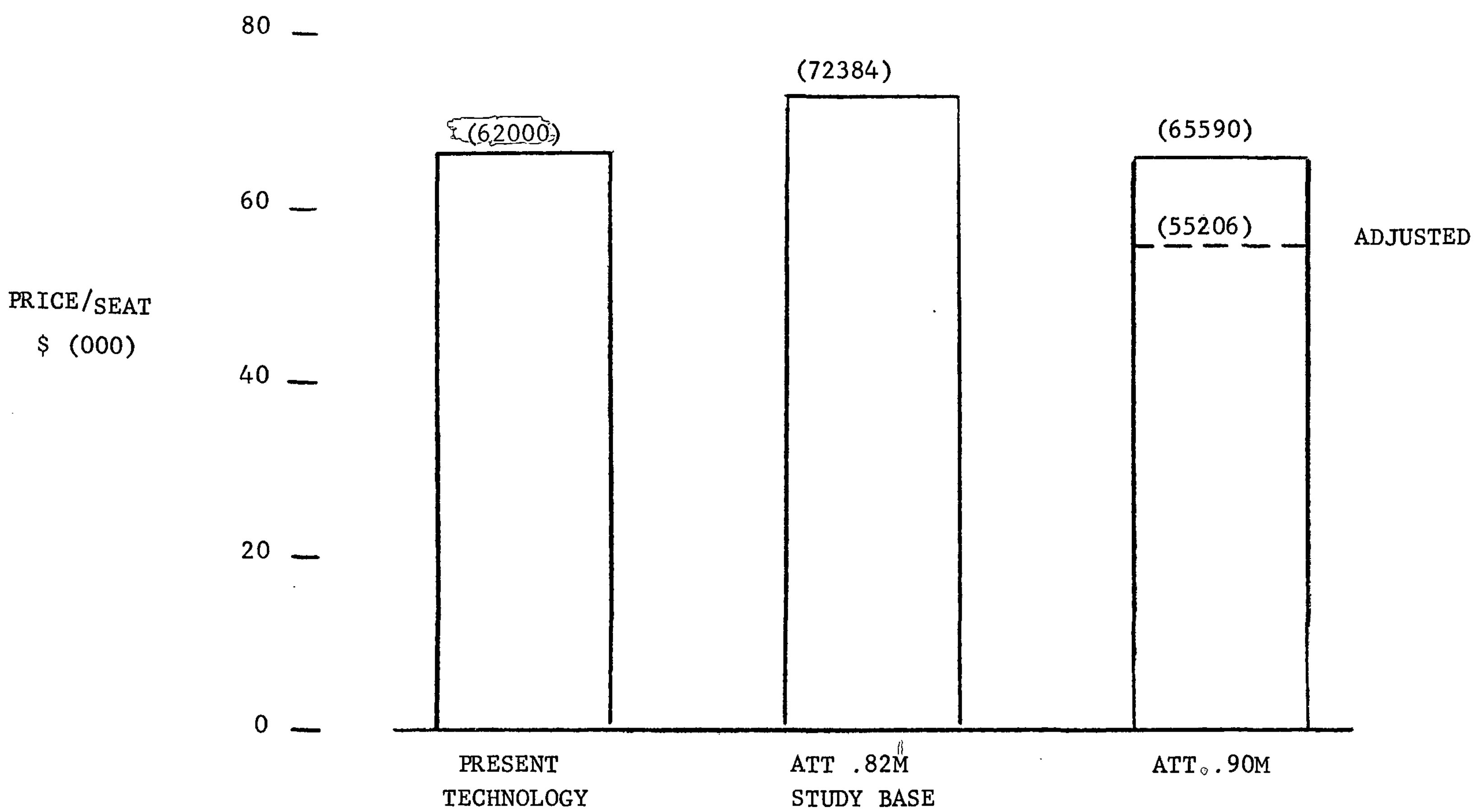


FIGURE 46
CONVENTIONAL AND ADVANCED
TECHNOLOGY COMPARISONS
(195 SEATS)